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OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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Terrestrial Magnetism	*Otto Klotz*	157
Calendars, Ancient and Modern	*Albert D. Watson*	172
Darwin's Tidal Theory	*A. J. Dempster*	185
The Orbit of σ Geminorum	*W. E. Harper*	200
Stereographic Projection Tables	*Otto Klotz*	205
Meetings of the Society		
At Toronto	*L. G.*	216
At Ottawa	*C. E.*	217
At Hamilton	*T. H. W.*	221
At Guelph	*J. T. L.*	222
Notes from the Meteorological Service		
Report of the Weather in Canada, April-May	*R. F. S.*	225
Magnetic Observations	*R. F. S.*	228
Earthquake Records at Toronto and at Victoria, B. C.	*J. V.*	230
Astronomical Notes		
The Place of Comets in Cosmogony		232
Total Solar Eclipse of April 28		232
Mechanical Production of Streamers seen in the Solar Corona		233
Heat and Light of Meteorites		233
Nova Lacertæ		234
Motion of Calcium Vapor Over Sun-Spots		235
Nature of Inertia		237
Migrating Stars		237
Wolf's Comet		237
Tidal Actions	*J. R. C.*	238
Book Reviews	*ô.*	239
Notes and Queries	*C. A. C.*	240

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TERRESTRIAL MAGNETISM*

BY OTTO KLOTZ

IN my brief address I could probably tell you more about what is not known about terrestrial magnetism than what is known.

What a compass needle is you know as well as I do. Let us get at a few fundamental ideas about our subject. Here I suspend a short piece of thick iron wire at the middle, its position is horizontal and it will point in any direction into which I place it. I will now bring two magnets into its vicinity, opposite poles of the magnet facing each other and equidistant from the iron rod. What happens? Nothing has come in contact with our iron rod, yet it has moved and placed itself in a definite direction which we find is in line with the two poles of the magnet. Some mysterious and unseen hand seems to have taken hold of the iron wire and turned it into a particular position. There is now something in the air or ether about the wire that wasn't there before, we call it a magnetic field. It seems as if parallel bands stretched between the poles of the magnet and between

* Address delivered with experiments, before the Royal Astronomical Society of Canada, at the Observatory, Ottawa, on October 13, 1910.

which the iron is forced to place itself. These bands we call magnetic lines of force. Nature always takes a short cut, follows the line of least resistance. Water follows the line of greatest descent down a hill side, lightning takes the shortest cut to kill itself, and so our magnetic lines of force take the easiest path, which is through the iron and through the longest course of the iron, for the iron furnishes an easier path than the air. If we suspend a square disc of iron the direction it would assume between the poles of our magnets would be along a diagonal. We are justified then in speaking of magnetic lines of force. I said that the iron rod places itself in line with the poles because it offers an easier path for the lines of force to pass from one pole to the other than does the air. There are substances, however, that offer more resistance to the passage than does air, and as we may hence rightly conclude the particles will so place themselves when free to move that they will likewise offer the least resistance to the lines of force, which, of course, means that such substances will be at right angle to the line of force as seen in the experiment with bismuth.

Our experiment with the iron rod would have been equally well, in fact better illustrated, had I taken a piece of magnetised steel wire, but a phenomenon would have been introduced that I wished to avoid for the moment, and that is, that our magnetised wire or needle as I shall hereafter call it, would have placed itself not only in line of the poles of the magnets, but as it has two poles itself, its poles would have faced poles of opposite polarity of the magnets.

We know that the compass needle at any given place has, temporarily, at least, a definite direction,— that is, it places itself in the direction of the lines of force in the magnetic field. From our experiment and what has been said we might conclude that there are some magnets somewhere on the earth that produce these lines of force. But if we were to attempt to give a position to these terrestrial magnets we would meet with difficulty. It is found that this directive property exists all over the earth, so that our magnets would have to satisfy all the directions shown

by the needle around the pole. It is scarcely necessary to mention that these lines of force have no force of translation, the force they exert is that of a couple, *i. e.*, a turning about a point, like the force exerted on the handles of a letter-press. From observations with the compass needle we must conclude that if the earth is not a magnet, it at all events, behaves like one, and that lines of force traverse the surface in approximately a north-south direction.

Now let us see whether we can offer another explanation for these lines of force. Let us see whether we can effect this directive influence on our needle in another way than by means of magnets.

We have here a coil of copper wire wound around a cardboard cylinder. We shall suspend on a silk thread within, a thin strip of soft iron evenly balanced. You will notice that it will remain in any horizontal position in which it is placed. I shall now send an electric current through the copper wire — and see what happens. Our iron strip has placed itself in a definite direction, that direction bearing a definite relation to the plane of the windings of the wire. Our iron strip finds itself again in a magnetic field with its lines of force along which or parallel to which the strip places itself. If instead of the iron strip, which ordinarily is free from magnetism, we use this magnetised needle, it would have behaved similarly, but as the needle has magnetic poles the total field is intensified, and furthermore, we find that the relative position of the poles to the coil is dependent upon the direction of the current, that is, they are reversed by reversing the current, as you see.

In this experiment it is to be observed that our needle is subject to the magnetic field of the earth urging it into a particular direction but the field of the electric current is so much stronger, that the terrestrial force is for the moment negligible.

We have shown then that we can produce a magnetic field without the use of magnets. An electric conductor is surrounded by a magnetic field to which the conductor is concentric and the lines of force are tangent to concentric circles in the plane per-

pendicular to the conductor. Hence the phenomenon of a compass needle always placing itself in an approximately N–S direction can be explained too by supposing currents to circulate about the earth approximately in the planes of the parallels of latitude. If they circulate within the earth the direction the needle would take at the surface would be the reverse of that if the currents were above or without the earth. By Ampère's rule or law we know the relation between the direction of the current and the deflection of the needle by the current, and the deflection of the needle by the current. From the behavior of the needle on the earth that the end that is deflected to the north is also deflected downwards in that direction shows, that if the directive force of the needle is due to electrical current, such current must be within the earth, where too is situate, of course, the magnetism attributable to the magnetised particles which form part of the earth itself. We are safe in saying then that the chief seat of magnetism is within the earth. In connection herewith we may give an example how investigations in one department of science may give results applicable in another department of science with which it is apparently wholly unconnected as, for instance, magnetism and seismology. What have earthquakes got to do with a surveyor's compass? Apparently nothing. Let us see however. Our seismograms or records of the pulsations or waves propagated by earthquakes give us a clue to the constitution of the earth. Earthquakes propagate three distinct types of waves, longitudinal, transverse and surface waves and the velocity with which each is propagated depends upon the properties of the mass or substance through which it is sent, such as density, elasticity, resistance to deformation and compression. From the examination of many seismograms from different quakes, Professor Wiechert is led to the conclusion that the earth is in the main, composed of an outer stone shell or mantle of about 1500 km. thickness, and that the nucleus, or central part, is essentially iron. If such is the case we may find therein a close association with the phenomenon of terrestrial magnetism, and the pointing of the surveyor's compass.

Knowing now the directive property of a magnetised needle when free to move horizontally we will devote but a moment to the method of determining that direction with reference to the cardinal points of the earth.

The simplest way is, of course, with the compass itself. If we point the sight line of the two uprights along the true north-south line, the pointing of the needle gives directly the deviation of the magnetic from the true north on the graduated circle. The accuracy of such readings is, however, probably not greater than 10 minutes of arc. More accurate readings may be obtained by having a long trough containing a needle attachable to a surveyor's transit-theodolite, the trough being supposedly parallel to the line of sight of the telescope, so that when the needle points to the zero of the trough the angle of the line of the telescope with the meridian gives the magnetic declination,—as it is called,—variation of the compass as formerly designated. A more accurate method, however, and one used by us in our magnetic survey of Canada is to observe on the magnet direct with a telescope, either on a magnet supported in a pivot like the surveyor's compass or on a magnet suspended by a fibre. In either case the magnet is supplied with a small mirror by which the thread in the line of sight of the telescope is reflected. Both forms of magnets must be invertible to eliminate the mirror correction, or its deviation from a right angle to the line of the supported or suspended magnet, that is, of the magnetic axis. The pointings of the telescope are read off on the horizontal circle of the instrument, upon which too, the pointing of the telescope for true north is found by solar or stellar observations, with which you are familiar. About the suspended magnet a point must be noted. It will only place itself in the magnetic meridian if there is no twist of torsion in the suspending fibre or thread. Hence this twist must be removed before we can get reliable results.

Columbus was the first to establish the fact that the needle does not point true north and south, and furthermore that its

deviation therefrom is different for different places as he found when sailing across the Atlantic and discovered America.

So far we have only spoken of the horizontal direction of the needle. Three quarters of a century later than Columbus, in 1576, Robert Norman discovered the property of the needle which we call dip or inclination. A compass needle which is horizontal at a given place when transported north or south no longer is horizontal, but is tilted, in the first case the north end dips down and in the second tilts up. We have thus discovered a new element in terrestrial magnetism,— dip or inclination. To measure it we must permit our needle to move freely up and down, *i. e.*, in a vertical plane, and evidently in the plane of the horizontal pointing or magnetic meridian. This down-pointing of one end of the needle intensified the belief that there must be something, some magnetic matter within the earth to produce this effect. How accurate observations for inclination are made I shall illustrate with one of our Dover Dip Circles.

That terrestrial magnetism is due to electric currents within or without the earth, the fact of the inclination where the north end dips (in the northern hemisphere) downwards would indicate the direction of the current to be from east to west and within the earth. Slowly and by degrees the phenomena of terrestrial magnetism were observed and recognised, for it is one thing to observe and another thing to recognise what has been observed. It is by comparison of similar observations that an opportunity is afforded of studying changes, if any, and their significance.

It is obvious that the discovery of secular variation could not have been made until the lapse of a long time after observations were first recorded. It was thus that Gellibrand in 1684 discovered that through lapse of time the pointing of the needle at a given place changes, that is, that there is secular variation.

This secular variation is another of the unsolved problems or riddles of terrestrial magnetism. Permit me to resurrect Halley, whose name recently dipped beneath the horizon for another 75 years. Halley was a great scientist in his day, travelled extensively, observed and paid much attention to

terrestrial magnetism before he assumed the part of Astronomer Royal in succession to Flamsteed. In a paper presented to the Royal Society, in 1692, entitled "On the change of the Variation of the Magnetic Needle, with an Hypothesis of the Structure of the Internal Parts of the Earth," he says:

"Having published, in those Transactions No. 148, a theory of the variation of the magnetic needle, in which, by comparing many observations, I came at length to this general conclusion, viz.: that the globe of the earth might be supposed to be one great magnet, having four magnetical poles or points of attraction, two of which near each pole of the equator; and that in those parts of the world, which lie near any of those magnetical poles, the needle is chiefly governed thereby; the nearest pole being always predominant over the more remote. And I there endeavored to state and limit the present position of those poles on the surface of our globe. Yet I found two difficulties not easy to surmount: the one was, that no magnet, I had ever seen or heard of, had more than two opposite poles; whereas the earth had visibly four, and perhaps more. And secondly, it was plain that these poles were not, at least all of them, fixed on the earth, but shifted from place to place, as appeared by the great changes in the needle's direction within this last century of years, not only at London, where this discovery was first made, but almost all over the globe of the earth; whereas it is not known, or observed, that the poles of a loadstone ever shifted their place in the stone, nor, considering the compact hardness of that substance, can it easily be supposed." As we see, Halley's difficulty of interpreting the phenomena was that he conceived the magnetic phenomena to be due to four poles instead of two, for there are only two as far as declination is concerned; the other two poles of which we now speak are those of maximum total intensity. In order to give a plausible if not quite satisfactory explanation to account for the secular variation he conceives the earth to be made up of two concentric spheres revolving in nearly the same time. In his words "Now supposing such an internal sphere, having such a motion, we may solve the two great diffi-

culties in my former hypothesis. For if this exterior shell of earth be a magnet, having its poles at a distance from the poles of diurnal rotation ; and if the internal nucleus be likewise a magnet, having its poles in two other places distant also from the axis ; and these latter, by a gradual and slow motion, change their place in respect of the external, we may then give a reasonable account of the four magnetical poles, as also of the changes of the needle's variation. The period of this motion being wonderfully great, and there being hardly a century since these variations have been duly observed, it will be very hard to bring this hypothesis to a calculus. . . . . Hence and from other of like nature, I conclude, that the two poles of the external globe are fixed on the earth, and that if the needle were wholly governed by them, the variations would be always the same, with some little irregularities on the account just now mentioned ; but the internal sphere having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive or directive power of each pole ; and consequently there must be a period of the revolution of this internal ball, after which the variations will return again as before. But if it shall in future ages be observed otherwise, we must then conclude, that there are more of these internal spheres, and more magnetical poles than four, which at present we have not a sufficient number of observations to determine, and particularly in that vast Mar del Zur, which occupies so great a part of the whole surface of the earth."

The riddle of secular variation is not much nearer solution to-day than it was in the days of Halley. About a century and a half after Halley, the illustrious Gauss applied his mathematical skill to terrestrial magnetism and put the subject into a mathematical and scientific basis. Especially did his labors result in expressing the terrestrial magnetic force or intensity in absolute units in contradistinction to the relative values that had obtained before. Gauss was essentially a mathematician and not a physicist. To show the state of knowledge with reference to secular variation in the time of Gauss we may cite the following extract.

In the closing words of a letter in 1832 by Gauss to Schumacher the former says regarding secular variation: "I have always considered those vast changes as something most remarkable. Terrestrial magnetism is without doubt not the result of the presence of a pair of large magnets in the vicinity of the earth's centre, which by degree move away many miles from their position, but is the result of all the polarized iron particles, and especially of these that lie nearer to the surface than to the centre. Yet, what shall one think of the vast changes that have taken place within a few centuries? Cordier's hypothesis of a relatively thin crust has always appealed to me as explanatory of the above phenomenon. Of course, in that case the magnetic elements can have their seat only there, and the thickening of the crust from a former fluid state would then readily explain the large variation in the terrestrial magnetism, which otherwise remains a great riddle. The circumstance too, that the so-called principal magnetic poles lie in the coldest regions, where we may take for granted that the crust is thickest, seems to point in that direction."

Wiechert who gives the above quotation in the Göttingen "Festschrift 1906," adds "that it is a consolation for many a scientist who is so painfully aware of his own inability to explain things, that Gauss could entertain such naive notions. It is to be noted, however, that Gauss wrote these words in a private letter, and that he was very cautious in weighing every word that was intended for publication."

As I have already said we know nothing of the law that governs the secular variation nor have we as yet the record of a complete cycle for any place and hence can not predict what the variation is going to be in advance. Even when we know the secular variation for a given place, say Toronto, which has one of the best and longest magnetic records in the world, we cannot with certainty apply that variation to a comparatively near place, say Ottawa.

A lot of mathematics has been expended, wasted I may say, in squeezing every secular variation curve into a harmonic for-

mula or harness, that is, we make a formula for what we already know from direct observation. Unfortunately the moment the curve sticks out beyond our harness we lose control of it, in short, we cannot extrapolate as I have found again and again. However, we can interpolate with a fair degree of approximation the value of the declination of any place lying between stations, not too far apart, whose values have been observed. When I speak of approximation I mean values within say 5 to 10 minutes of the true values. This excludes, of course, the effect of local attraction which may run into degrees, many degrees. The secular variation is not the same for different places, nor does the period of the cycles as far as we can judge from the limited data at hand, appear to be the same for different places.

Prometheus is still bound.

We have so far spoken of the horizontal direction of the needle, or declination, and of the direction in a vertical plane, or inclination, dip. As we have seen, a force is acting on the needle to put it into some definite position. That force, whatever it is, must have magnitude, must have intensity, must have strength. This is the third element which we have to determine in order to express terrestrial magnetism completely.

The most obvious way to measure this strength is to apply a given weight to one end of a dipping needle at a known distance from its axis and observe how much the needle is pulled out of its former position; we here compare the gravitational force with the magnetic force. In principle this is very simple. The method was formerly used to determine relative intensity between different places on the assumption that the magnetism of the needle remained constant, for it must be remembered that when the weight spoken of above is pulling the needle, it is pulling against the combined strength of the magnetised needle and of the magnetic field of the earth. It is the latter that we are seeking.

There are other and more accurate methods that we use and of which I shall simply indicate the principles involved in order to make clear how the intensity is arrived at and expressed in

absolute units. Perhaps a word here about absolute units may not be amiss. They are independent of our earth and are applicable anywhere in the universe. A moment ago I spoke of attaching a weight to the dipping needle ; suppose the weight to have been a gramme giving a certain deflection of the needle from its normal position. Now let us suppose we carry our needle to some other planet, Mars, where the magnetic strength and inclination are the same. Let us again attach our weight, it will then be found that our weight will not deflect the needle the same number of degrees as before. Why ? because our gramme weight does not weigh the same on Mars as on the earth. If, however, we had expressed our gramme not as weight but in absolute units of mass and acceleration we would have been prepared to launch anywhere in space and make comparisons with any other force. The fundamental units generally applied are length, mass and time. Weight as we understand it on the earth, is simply mass under the accelerating influence of the earth, which as you know is about 32 ft. per second, per second, or about 980 centimetres. As soon as we leave the earth, weight loses its significance, while mass remains. So that if we provide ourselves with a unit-length, a unit-mass and a unit-time we can traverse not only the whole earth but the whole universe and make observations which are strictly and directly comparable.

As unit of length is taken the centimetre, as unit of mass is taken a centimetre cube of water, called a gramme, not of weight but of mass, and as unit of time one mean-time second. Together they are spoken of as the C. G. S. system of units.

I trust this brief digression will show the use and desirability of expressing magnitude,— intensity in this case — in absolute units.

To return now to the method of measurement of the intensity of terrestrial magnetism.

In an address on " Gravity " a year or so ago, I showed how the intensity of gravity was measured by noting the time of oscillation of a pendulum ; the greater the gravity the more rapid will be the oscillations. Gravity is continually striving to pull

the pendulum into its line or direction of action, that is, into the vertical.

Now if we suspend a magnet by a fibre so that it it free to move horizontally it will place itself in the magnetic meridian. If we displace it from this position, *i. e.*, displace the poles symmetrically with reference to their zero position, the magnetic force acting as a couple will force them back, the potential energy at the points of elongation or amplitude of the displacement is converted into kinetic energy, with the result that we obtain oscillations of the magnet, quite similar to the oscillations of a pendulum. The magnetic strength that comes into play in producing these oscillations is composed of two parts, that of the magnet and the horizontal component of the earth, that is, the product of $m\ H$.

In our next operation we will deal with these same two quantities but in a different manner. We will match them against each other. We will use the same magnet that oscillated and get it to act on another and suspended magnet which is, of course, under the influence of the earth's magnetism ; we shall observe how much the suspended magnet is deflected from its normal position when the deflecting magnet is at a given distance from it and in the same horizontal plane. These observations are made on each side of the deflected magnet, and at different distances. Suffice it to say that such observations give us the ratio $\frac{m}{H}$, and as we have found the value of the product, the value of H is readily found. This is the horizontal component of the earth's magnetic intensity, and the total intensity is H Sec. θ, or the horizontal intensity multiplied by the secant of the inclination.

This apparently finishes our determination of the magnetic elements ; we have found the declination, the inclination and the intensity. We seem to be sailing now in smooth waters with our captive data, but, alas, there are breakers ahead. We have noted the time of the day, month and year when our observations were taken. We repeat them at the same place but at a different time, and we find differences from the former values.

It is nearly two hundred years ago, in 1722, that Graham, the well-known clock-maker of London, discovered by a long series of observations the diurnal variation of the compass.

The diurnal variation in declination has given rise to a good deal of investigation and research without, however, yet fully elucidating its cause or the laws that govern it. However, it has been satisfactorily established that this variation is due to influences outside the earth, while that of the secular variation is nearly wholly within the earth. The diurnal variation is, undoubtedly, closely bound up with the sun and the rotation of the earth, for the local time when the needle reaches its daily eastern and western elongation does not differ much for all places over the earth. It is obvious that whatever the solar effect on terrestrial magnetism, it must be less on the side of the earth away from the sun, that is, where it is night, than upon the side facing it. A similar phenomenon is produced and has been observed during an eclipse of the sun.

The magnitude of the variation however differs. This might be inferred from the fact that as the horizontal force decreases towards the poles the electric influences, whatever they may be, would be more effective in deflecting the compass needle in higher than in lower latitudes. This diurnal variation fluctuates too, somewhat throughout the seasons. Here at Ottawa we have about 10′ to 12′ diurnal variation. In the morning about half past seven the needle points farthest to the east, it crosses the average magnetic meridian about half past ten, and reaches its extreme western elongation at about half past one, when it begins to return slowly but not quite regularly to the east by the following morning.

It is obvious from this that a compass line run on the same bearing during a day cannot be a straight line, but is a sinuous one. However, the ordinary surveyor's compass does not read direction very closely anyway, so that for the kind of work for which the compass is used the diurnal variation may be neglected. It is there nevertheless.

There is an annual variation too, which must, however, not

be confounded with the annual change which is the progressive change in a year due to the secular variation. This annual variation is a negligible quantity, as the declination is affected in general by less than a minute of arc.

And lastly we have disturbances of the magnetic elements that are quite apart from terrestrial magnetism and about which we know very little outside of the phenomenon itself.

Unheralded they come, agitating the magnetic instruments not only at one place but the world over, to a greater or less degree, and disappear as mysteriously as they came. Ever since the periodicity of sunspots was established, their subtle influence was connected with these magnetic disturbance or storms; and, undoubtedly there is more reality than simple plausibility in this connection. What really happens on the sun we know not, although he is the dispenser of all life on this earth and of nearly all terrestrial phenomena. Various theories have been promulgated but as yet none satisfactorily. It is obvious that in these magnetic storms we have a magnetic field superposed on the earth's magnetic field, and as we have seen that a magnetic field may be produced by electric currents we are led to assume them to be the cause of such storms. Of the various theories may be mentioned that of Nordmann who suggests Röntgen rays from the sun, and hence the solar and terrestrial phenomena would be almost simultaneous; that of Birkeland, who believes the explanation to be found in kathode rays, the terrestrial phenomena following the solar in a few hours, and that of Arrhenius, who sees in the negatively charged particles shot out by the sun, the disturbing factor. In the latter case the interval of transmission to the earth might be two days or more. As you know, the Röntgen rays are not deflected by a magnet as are the kathode rays, hence we would expect the latter when approaching the earth to be deflected or bent. We may accept the general view that magnetic storms are produced by an outflow of solar energy, principally from sun-spot areas, while faculæ, solar outbursts and protuberances must not be overlooked. Whenever the earth is immersed in these jets or streams, a magnetic storm follows.

The manifestation of the latter has been hitherto considered simultaneous over the whole earth. Dr. Bauer, however, on close examination of the records finds an appreciable time-difference. He says: "The abruptly-beginning ones, in which the effects are in general small, are propagated over the earth more often eastwardly, though often at times westwardly, at a speed of about 7000 miles per minute, so that a complete circuit of the earth would be made in 3½ to 4 minutes. For the bigger and more complex magnetic disturbances the velocity of propagation may be cut down considerably."

As these storms are essentially a solar phenomenon while the atmosphere is the chief seat of terrestrial magnetic disturbances, we must look to the study of the sun, to a thorough investigation of its constitution, of its activities, of its daily routine, how it applies its forces day by day, month by month and year by year. When we know these things we shall then be in a position to interpret the manifestations thereof on our earth. We shall learn how and what solar emanations excite and stimulate the existing electric currents of our atmosphere. We naturally turn, therefore, to Mt. Wilson, California, where, under the auspices of the Carnegie Institution, Professor Hale and his able staff are carrying out solar research on so large a scale and in so thorough a manner. We should, after the work has been carried on over a sun-spot period of 11 to 12 years, be considerably nearer our goal of positive knowledge regarding the disturbances of the quasi-permanent magnetism inherent to the earth than we are at present. The perplexity of problems gives zest to the human intellect.

CALENDARS, ANCIENT AND MODERN

By Albert D. Watson

MEASUREMENTS of time based on the phenomena of nature were naturally regarded as peculiarly sacred by those ancients who worshipped the heavenly bodies. They venerated even the motions of the stars. This is not surprising to the open mind. Partial knowledge made them attentive to conspicuous rather than to less observed, though more significant, phenomena. It was natural that they should be impressed by sudden and brief but overwhelming exhibitions more than by changes that occupied long periods and made slow progress, requiring extended, systematic observation.

The calendars of the ancient world were based on the diurnal revolution of the earth; on the phenomena of sunrise, noonday and sunset, the periodic phases of the moon, its division into four quarters; on the four seasons with their wonderful variations of temperature and storms, thunder and dew, seed-time and harvest, and on all the multitudinous phenomena of the skies.

If we should suppose, however, that the primitive races were without knowledge as the result of observation, or devoid of interest in science, we should be in error. They may have been quite as scientific in spirit as ourselves though they had fewer instruments for scientific pursuit. They were not equipped as we are. The solar year was not accurately determined till the 16th Christian century and the ancients did not even know that the earth had a motion around the sun, yet the Egyptians of 4000 years ago had fixed the year as a period of 365 days, divided so accurately and wisely that it was copied by the French Commune a little over a century ago as being the perfection of year divisions; and the Chaldeans had a year of twelve months two thousand years before that.

The day was the simplest of all calendar periods. Some of the most civilized nations of antiquity had no hours, but only such divisions as were understood by the terms "dawn," "forenoon," "afternoon," "twilight," "evening," and the four watches of the night. The ancient Greeks divided the day and the night each into twelve equal parts and, as the parts were variable in duration, according to the season of the year, they were called temporary hours, summer hours, winter hours, etc. The Jews had hour divisions for the day, but many of the ancients had none.

The origin of the week is obscure. We cannot find any account of its beginning. It was probably, at the first, regarded as a quarter of a moon, and there is little doubt that this was its origin. The moon was a conspicuous object. Its motions were regarded as sacred. Its phases were observed by everybody. Naturally, one way of describing them was by stating what fraction of the disk was illuminated on any particular night. They did not understand the progressive increase and decrease of the moon's bright face, and had not, like the moderns, lost their interest in lunar phenomena.

Many of the ancients had no week in their calendar. The Greeks, for instance, had none, nor the Romans till after the reign of Theodosius. In fact, our own forefathers borrowed the week from the orientals and gave its days the names of their own deities. The people of the East numbered the days of the week. The Romans, who had no week, numbered the days of the month backwards from the calends, the nones and the ides.

The beginning of the day has varied with different peoples. The Chaldeans reckoned their day from sunrise, the Jews from sunset, the Egyptians and Greeks from midnight, and we follow the example of the Greeks in this matter. The beginning of the week has also varied. The Egyptian week began with Saturday, the Hebrew week with Sunday. Are we sure that the Jews in changing the beginning of the day and the beginning of the week did not also change the identity of some of the days. Is our first day of the week in this twentieth century the same day as was

accounted the first of the week by Hammurabi, king of ancient Babylon, or by Moses when he kept the flocks of Jethro on the pastures of Horeb? Is it the same as the first day of the Egyptian week known to Rameses II. in Heliopolis and Thebes?

Romulus established a year of ten months, following, it is said, the ancient Alban year. Each of these months was of the duration of a moon's age, so that, if we omit the added days, which were outside the ten months, the year of Romulus would be less than 300 days in length. Did these added days have names when the other days of the year had none? It is not likely. The Romans had no week and no week days. There could be no names for days if there were no months in these added days of the early Roman calendar. This seems to be an interesting field for investigation. It is well known that the Chaldeans (Accadians) had the week in their system 3800 years B.C., that the Egyptians had it 2000 B.C., that the Hebrews had it 1300 B.C., yet the Romans had no week whose days correspond with the days of the modern Jewish week. How did it come about that our first day of the week is the same as that of the Jews? The strong probability is that the Jews got their week from the Babylonians or the Egyptians and, no doubt, we got it in turn from them. The only doubt arises in the question as to whether the Hebrews would not purposely change the days of their hated captors and oppressors as they changed the first day of the week from Saturday to Sunday, and the beginning of the day from midnight to sunset.

The year has been a more difficult problem than any of the periods heretofore named. This is because of its natural division into a fractional number of days and moon-revolutions. The celestial wheels have no cogs. The earth travels a little too slowly for the convenience of the makers of calendars. If it completed its solar revolution in 364 days instead of in a little over 365 days — apparently an easy task — we should have a year consisting of exactly 52 seven-day weeks, and New Year's Day would no longer be a vagrant through the week as it is at present.

The ancients might have preferred to divide a year of 364

days into 91 four-day weeks. In that case, the time-table would have been written in part :—

24 hours	one day
4 days	one week
7 weeks	one month
13 months	one year.

Or they might have preferred 28 thirteen-day weeks, with a mid-week holiday. Then the table would have proceeded as follows:

24 hours	one day
13 days	one week
4 weeks	one month
7 months	one year.

Even this would not have exhausted the measures of so convenient a year. Knowing the period of the earth's solar revolution as exactly as we do, if we were making the calendar *de novo*, we should, no doubt, retain our seven-day week and establish a 28-day month, leaving the extra day of the common year with the leap year day outside the week altogether, somewhat like the five extra-month days of the ancient Egyptians, or the sixty similar days of the early Romans. In such a year, Sunday would fall on the 1st, 8th, 15th, and 22nd of each month and all other week-days in corresponding rotation.

The simple recurrence of days and dates in perpetual uniform relation makes such a calendar very desirable. Even the moon would then vary more regularly in relation to the month than now, but the whole year would be constructed on a solar basis. It would not matter when the extra days were intercalated. They might be made New Year's day and leap year day, the first and last days of the year, and have a festival character, giving the leap year day a highly religious significance.

Such a calendar was proposed in a paper which appears in the TRANSACTIONS of the Toronto Astronomical and Physical Society for the year 1896, on pages 59-72. The suggestion, then made for the first time, has been proposed since in a modified form, but nothing can be done till some family of nations acts co-ordin-

ately, realizing that all institutions however sacred were made for man and not for the honor of the ancient heathen deities. The gods have hitherto had the power to protect their calendars, but their power consisted in the partial knowledge and prejudice of the people.

The vital principle of any scientific calendar is the intercalated day which is a part of the year, but no part of the week. The need for such a division of the solar year appears when it is realized that at present we use fourteen different calendars, two for every day in the week, one of the two being for the common, and the other for the leap year.

Reform of the calendar is not excluded by the nature of astronomic law or motions, but by the inertia of conservatism, the *vis a tergo* which drives us on in the old courses, the skeleton hand of the past which holds us back when we would change or improve. There will, doubtless, some day be a thoroughly scientific calendar in use throughout the world. It is to be hoped that our own great empire that has laid the world under tribute so often in scientific enterprise will do so again. Meanwhile, we rest in the assurance that whoever *gets* the credit for devising a scientific calendar we, of the Royal Astronomical Society of Toronto, shall *deserve* it.

All historical beginnings are nebulous. The beginnings of the calendar are no exception to the rule. Sometimes the nebulæ out of which worlds appear are so distant and obscure that we cannot see them at all. It is the same with the beginnings of the almanac. Astrological works, copied from their ancient originals for the library of Assurbanipal, have been ascribed by recent scholars to the reign of Sargon of Accad, (B.C. 3800). In these documents the dates used show a year of twelve lunar months, a thirteenth being intercalated four times in eleven years. The order of the months is everywhere the same and the first of the year is Bar zig-gar which corresponds with the Assyrian Nisan and with our March-April period.

The Manda, probably the progenitors of the Medes, lived in the days of Sargon of Accad, and invented a four letter mono-

gram containg the initials of the four signs of the zodiac which at that date marked the four seasons. This monogram was used thousands of years afterwards by the Shemitic Assyrians. They recognized the sway of the sun and laid much stress upon the seasonal changes.

All Babylonian documents from the time of Hammurabi (B.C. 2200) show a fixed calendric system and a year beginning with Nisan. It has been suggested that, as the spring equinox corresponded, prior to Sargon's time, with a different zodiacal sign, it is possible that Nisan was the first month of winter when the calendar was made, and that season, and not the spring, may have then been regarded as the first of the year, as it is with us. Of this we can find no conclusive evidence. Much documentary testimony exists showing that the Greeks of an early date knew that the equinoxes move along the zodiacal belt.

There is little doubt that most of the early people established the year on a sidereal plan, thinking that such a system would also correspond with the seasons. The makers of the calendar, not knowing that the seasons change their relation to the stars as the centuries pass, supposed that in making the year begin with Nisan, they were binding that month permanently to the particular equinox or solstice then corresponding to it.

The Accadian months are lunar, yet their names show also a sidereal relation. Bar zig-gar, the Nisan of Accad, and our March-April month, signified "the sacrifice of righteousness" and the corresponding zodiacal sign was the ram, an animal much used in sacrifice. The Egyptians also introduced their sacred year with the spring equinox and the Aries sign. They too venerated the ram. The great temple of Amen-Ra at Thebes was approached through an avenue of ram-headed sphinxes. Did they find their sphinxes in the skies, or was the Egyptian ram transferred to the zodiac? To a modern observer, the latter proposition is the more likely. Khar-sidi was the second Accadian month. The word means "the propitious bull." Taurus is its sign. Kas was their third month and the name means

"twins." Gemini is its sign. It is, therefore, very clear that these months were named with reference to the stars.

The Egyptians had both a civil and a sacred calendar. Their civil year was solar and their sacred year sidereal. The former consisted of twelve months of thirty days each, with five days added at their close to bring the days up to 365. The French Commune adopted this system nearly 4000 years later as the best the world knew, even then. Not knowing the period of the earth's solar revolution, nor even the fact that it made such a journey, the Egyptians took no account of the hours, minutes and seconds which, as we know, complete the period.

The Nile dwellers fixed their great feast, The Festival of the Valley, on the 29th day of the second month of the inundation. This gave it a seasonal or solar relation. Their civil year began with Thoth in the autumn, and the Hebrews adopted the same season for the beginning of theirs. The Egyptian sacred year was sidereal, and Aries marked its beginning. In this also they were followed by the Israelites.

When the Hebrews left Egypt and instituted the Passover, they were commanded to regard the month Abib, then just begun, as the "beginning of months" that is as the first month of the year. This month was Nisan and was so called after the Babylonian captivity, though most of the other Hebrew months received Syrian names.

The Jewish year has always been, like that of the Babylonians, one of twelve lunar months and one intercalary month added, when necessary, to keep the year in proper relation with the seasons. At first the embolismic year was added once in about every three years. In later times, seven months were introduced in the course of every nineteen years.

There is evidence of the luni-solar nature of the Hebrew calendar in their earliest literature. "And God said, let there be lights in the firmament of heaven to divide the day from the night, and let them be for signs and for seasons, and for days and years. . . . And God made two great lights; the greater

light to rule the day, and the lesser light to rule the night. He made the stars also."

Where new moons were sacred, it became a matter of much importance to note the time of their appearance. A dweller in ancient Israel learned the time from signal fires upon the hills, or from runners who carried the news out from the large cities over the surrounding country. If there was any doubt of the day on which the thin crescent of the new moon appeared, it was necessary to keep two days that the right one should be observed at all hazards.

A new moon was never to be observed on a Sunday, a Wednesday, or a Friday. If a dweller in Zebulon, for instance, went out at night and saw the signal fire burning on Tabor's summit, he immediately proceeded to keep the feast of the new moon. If, however, the day was the first, the third or the fifth, he kept the following day. If a runner came to his house and told him that the silver crescent had been seen after noon and before sunset, the following day which began at sunset was the "new-moon" day, unless it was one of those on which a new moon was not to be observed, in which case the day following it was kept.

The embolismic month of the Jewish year is intercalated before the month Adhar, the last month of the sacred year, the month immediately before Nisan. The Jewish common year had three forms.

1. The ordinary or regular common year of 354 days.

2. The imperfect or defective common year in which the third month, Kislev had only 29 instead of 30 days, and the year had 353 days.

3. The perfect or abundant common year of 355 days, in which the second month, Marhesh-wan had 30 instead of the usual 29 days. Similarly, there were three embolismic years corresponding to these and consisting of 384, 383 and 385 days respectively.

The Jewish calendar, like all religious institutions with fea-

tures peculiar to themselves, is assured of perpetuity as long as the religious system endures which gave it its origin. When all separating walls are broken down, when the races and their institutions are all thrown into the melting-pot and the pure gold of humanity issues refined and unified into one homogeneous expression of life and its highest uses, who can tell whether there will be more or the Jewish or of the Gentile institutions in the new regime?

The ancient Arabian calendar was purely lunar. Its year consisted of 12 lunar months with no intercalation to keep them in constant seasonal relation. Their year retrogressed through the four seasons in about 32½ years. Arabian or Mohammedan years are arranged in cycles of thirty, nineteen of which are common years of 354 days each, and eleven are intercalary years with an additional day appended to the last month. This brings the average duration of the Mohammedan month to within 2·8 seconds of an astronomical mean lunation, an error which would amount to a day in about 2400 years.

The pilgrimage to the Kaaba took place in early times in the last month of the year. Necessarily, this pilgrimage would take place 11 days earlier at every recurrence. When it fell so early as to come before the harvest, the pilgrims had difficulty in getting enough food for their journey. The date of the pilgrimage could not be changed, being too sacred. The calendar was, therefore, modified by a process which made the year luni-solar and brought the pilgrimage always in the autumn.

Four of the Mohammedan months were sacred. They were the first, second, seventh and twelfth. Three of the sacred months being consecutive, the fiery-hearted Arabs could do no fighting for the whole period of three months till Mahomet came to the rescue and interpreted this restriction as meaning that they could only fight with Mussulmen in these months. He then led an expedition against the heathen himself, and the situation was no longer intolerable.

China, like nearly all the eastern nations, has a lunar calendar. The months are alternately 29 and 30 days in duration, and begin

when the moon is between the sun and the earth. The year begins and ends when these three bodies are in the same relation. The Chinese add a thirteenth month to the year after every thirty lunations. Such a plan does not keep the year in consonance with the seasons, therefore instructions have to be issued relating to planting, reaping, fishing and hunting. This accounts for the great bulk of the Chinese almanack, which is said to have the largest circulation of any book in the world.

The almanack for the year which closed February 9th, 1910, shows that year to have had 13 months, a first month, a second month, an intercalary second month, then a third, fourth, fifth, etc., to the last, which is considered as a twelfth, but is in reality a thirteenth month. As the intercalary second month of that year contained only 29 days, the whole year contained 383 days. The common twelve-month year contains necessarily 354 days.

In ancient times, the Chinese years were named after certain animals. Even the hours were so named. A Chinaman will sometimes even yet tell you he was born in the dragon year or in the dog year. Clocks are still running which strike the hour of the rat or the horse. Expressions such as "before horse" or "after horse" meaning before or after noon, were in use. Noon was "full horse" in the old days.

The Chinese have devised a most ingenious clock which is so explicit that the observer may see, for instance, on its dial that he is looking at a Chinese clock in the first hour of the first day of the first month, which consists of 29 days, of the 48th year of the 76th cycle of 60 years, which is also the 2462nd year of Confucius, the third year of the Emperor Hsaun Tung, the 4548th year by the sexagenary system, the 4608th from the time when Hwang Ti ascended the throne, and which corresponds most nearly with our year 1911.

The Chinese hour has 120 minutes, the noon hour being the period between 11 a.m. and 1 p.m. of our time. This is the horse hour of the ancient calendar. The time from 11 p.m. to 1 a.m. is the rat hour. Half of these hours was a.m. and the other half was p.m.

A notable contribution to the calendar was made when the Athenian astronomer, Meton, observed that 235 lunations correspond in duration almost to an hour with the period of 19 solar years. In fact, there is only 1·5 hours of difference between 235 lunations and 19 Julian years. It may help us to understand how some of the ancients arrived so near to final truth respecting heavenly motions, if we remember that, long before the time of Meton, some Babylonian sage had discovered the *Saros*, a cycle consisting of 6585 days and 8 hours, during which period there are 223 lunations. The period consists of 18 Julian years, 10 days and 18 hours. At the end of this period all eclipses are repeated nearly as before. The computation of eclipses and all recurrent luni-solar phenomena was much simplified by the discovery of this cycle.

The practice of intercalation is common to all calendars and is necessary in order to make the year solar and seasonal. The Aryans have always been more disposed to favor the solar, the Semites, the lunar, division of time. The moon loses sway over intelligent people, while the uninstructed still tend to regulate their times and seasons under the guidance of the lunar phases. The Hebrews are immensely clever but the progress of a race is sometimes inhibited by its traditionalism.

A few words as to our own calendar. Our day names were derived from the Scandinavians. The week came to us from the Jews, the month and the year from the Romans. No institution was ever more subject to whim and caprice than the Roman calendar. The ten months of Romulus became twelve under Numa, who added January and February. The year was now one of 354 days, having 12 months of 29 and 30 days alternately. Then a day was added to make the number odd because odd numbers were accounted more propitious. A month of 22 and 23 days alternately was intercalated between the 23rd and 24th of February in every second year. The average number of days in the year was now 366½. Later the intercalary month was omitted in every 24th year. This made the year average almost solar.

After this, the priests seem to have had power to increase or diminish the days of any year at will under any plausible pretext. Their plan was to postpone an event or hasten it without changing its date. They intercalated days at will. No one knew just when a year would begin or end. This continued till Julius Cæsar found the year A. U. C. 707 so disordered that it was necessary to add two months, though it was already a year of thirteen months. He thus made it a year of fifteen months being 455 days.

The average year was now fixed at 365¼ days by giving the odd months 31 days and the even ones 30 days. The exceptions to this rule were the common years when February had only 29 days. Even now the priests seemed not to have enough intelligence to carry out Cæsar's orders and their mistakes had to be corrected in the next reign. But Augustus, wishing to be accounted a patron of science, imitated Julius Cæsar by having August named in his honor as July had been named after his predecessor. But August had only 30 days and July had 31. Why should the month of Augustus be briefer than the month of Julius. This was an indignity not to be suffered, so another day was taken from the already long-suffering February and added to August. Then, that there should not be three 31-day months in one quarter, one day of September was pushed on into October, and the 31st day of November was pushed on into December and, lo, we had our calendar. It has always been called the Julian calendar, but if the great Cæsar had known what anomalies his successor had introduced, he would have disowned it, and the least the world should have done was to have restored the Julian calendar to the state in which Julius Cæsar intended it to remain. This should be done now and without the least delay. The Julian calendar is clumsy enough with all the improvement of the Gregorian reforms, without the silly meddlings which have made it a curio for all time.

The Gregorian amendments to the calendar are described in a thousand books, almanacks and cyclopedias, and though a worthy and helpful reform, need not be explained here. Just

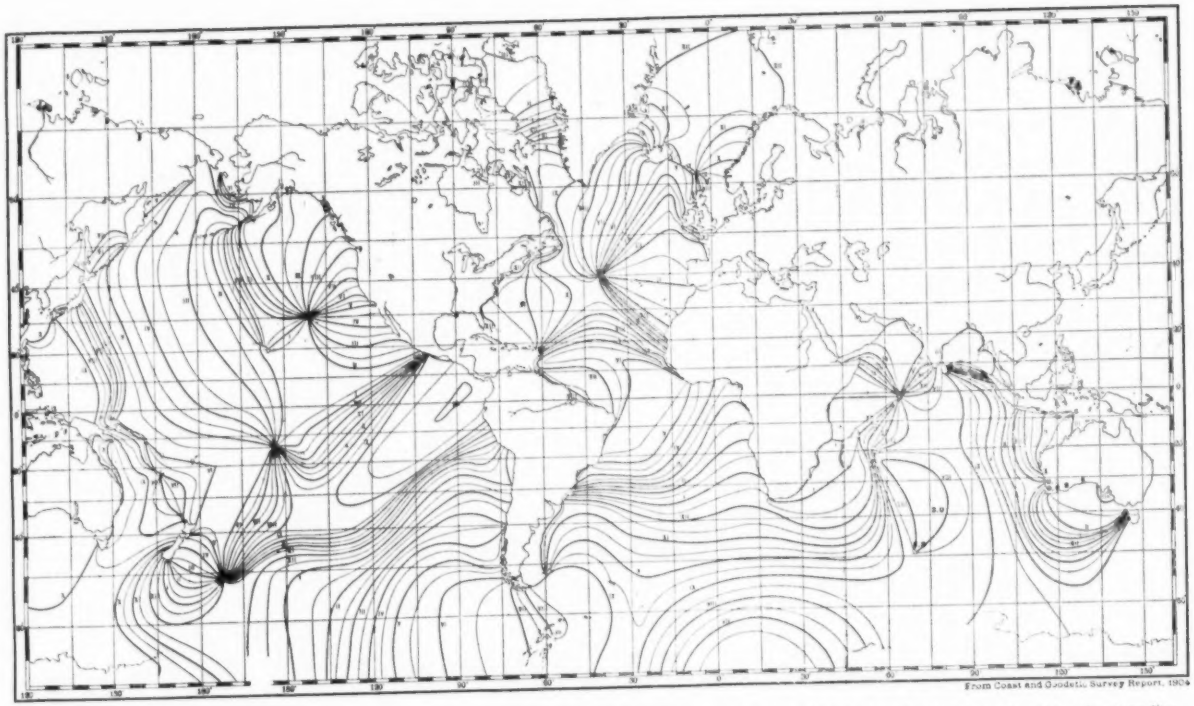
this observation, however, may be made. We speak of the Julian and Gregorian calendars. Cæsar and Gregory were the instruments by which these were adopted, and are to be commended. Perhaps, it is well to remember, however, that the astronomer Sosigenes was the author of the Julian calendar and that the Italian physician, Aloysius Lilius, devised the Gregorian reform, but died before its introduction.

DARWIN'S TIDAL THEORY

By A. J. Dempster

IN any treatment of the subject of the evolution of stellar systems, "Darwin's Tidal Theory" rightly has a place. For, although it is now about thirty years since the basis for the considerations that go under that title was laid by Darwin, yet those considerations still have weight in all theories of cosmogony. The Theory is fundamentally not a *theory* at all, but the drawing of attention to actual phenomena; and even if the Laplacian idea of a contracting nebula leaving rings behind is to be abandoned, yet the facts which Darwin first discussed must still be considered and applied, perhaps in fields not at first contemplated. In recent years the Theory has been attacked strongly, and it is interesting to see how it has stood under these assaults. Also the historical side is full of interest, for here especially we see how apparently insignificant phenomena may be suggestive of important processes.

The Theory commences with a consideration of the results which must follow from the fact that the tides are continually passing across the oceans. If Professor Leacock were an astronomer we might suspect an element of satire in his humorous sketch which gives the "Remains of Astronomy" that an educated man is supposed to carry around with him: "Astronomy teaches the correct use of the sun and planets. These may be put on a frame of little sticks and turned round. This causes the tides, etc." For if we look at our map which has been constructed from tidal observations taken all over the world we see how very different the phenomena are from the simple idea of two "bulges" following each other around in regular procession. There appear to be several centres about which the tides circle; at some places they move fast and at others slow; while at some places the tides sweep backwards. We may judge how far the simple theory is



Cotidal Lines of the World.--Those places on a continuous line have high tide at the same time. The high tide which is along line I, will one hour later, be along line II, two hours later along line III, etc. The points to which the lines converge are places of NO tide.

inadequate when it has been suggested that the tides may in part be due to the crust of the earth rocking a little; or that an important consideration may be that certain parts of the ocean are of the proper depth to oscillate in unison with the disturbing force, thus causing great oscillations which disturb the ocean all around.

But this is aside from our subject. We are directly concerned with the fact that the tides are constantly sweeping across the oceans, moving large masses of water, wearing away channels, in short, overcoming friction and thus doing work. The energy thus expended must come from the mechanical energy of the bodies affected. Mr. W. D, McMillan* has recently given a rough estimate of the amount of energy used up by the tides. He estimates that the work being done is equal to about 200 million horse-power. That is about as much energy as would be expended by 40 Niagaras.

Coming to the basis of our considerations, let us ask, Where does the energy come from? and What consequences follow from this constant using up of mechanical energy? As the sun is of little account in the matter of the tides, we may consider our earth and moon as constituting a system by itself. In this system we see that there are three storehouses of energy that may be drawn upon. First, there is what we might call the "earth-fly-wheel." Just as energy is stored up in the fly-wheel of an engine, so energy is stored in the rotation of the earth on its axis. We can calculate roughly the amount of this energy. The earth is so large and rotates so rapidly that the energy comes to an enormous amount. If we took away energy from it at the rate at which tides do work, or at the rate of 40 Niagaras, it would not run out for 44 billion years. No wonder the problem of making the earth do all our work has always appealed strongly to the imagination of daring inventors. If the energy were used in warming up the earth itself, the temperature would be raised about 170° Fahrenheit.

But this is not all the energy in our earth-moon system.

* *Publications* of the Carnegie Institution of Washington, No. 107, p. 71.

Energy is also stored in the revolution of the moon about the earth. We might call this the "moon-fly-wheel." The energy here is about one-sixth that in the "earth-fly-wheel." Again, there is a third source. Energy is stored in the actual position of separation of the two bodies. For if we have two bodies joined by a stretched spring, work may be done by the spring pulling them together. Thus here the pull between the earth and moon makes their position of separatioa a source of energy. The energy thus stored is twice that in the "moon-fly-wheel," or about one-third that in the rotation of the earth.

We might compare the earth to a young man with three sources of income. The young man has a large bank account of his own, corresponding to the earth's rotation. He has a rich uncle, the moon, who can supply him with money — the orbital energy. His uncle has also, corresponding to the separation of the two bodies, put a large sum in trust for him. The young man is very extravagant and the question is, "Where does the money come from?" Our metaphorical young man is not free to do as he pleases. We shall see that he draws on his own bank account, and also borrows from his uncle, but that the total is more than he wants and so he puts some of it away with the amount already in trust for himself. That is, the effect of the tides is to take energy by slowing up the rotation of the earth and the revolution of the moon, and to store a part of this energy by 'shoving' the moon further away.

Before the time of Darwin, it was thought that the chief effect of the tides was to slow up the rotation of the earth. Thus Kant and Laplace had explained the fact that the moon always keeps the same face toward the earth, by saying that tides raised in the moon by the earth long ago had completely stopped its rotation relative to us. Darwin showed that, besides this effect, there were others of much more interest.

It is not possible in this paper to do more than indicate results of investigations, but we are all familiar with the two principles on which is based the solution of this problem. One is Kepler's third law, which tells us the connection between the

distance of the moon and the period of its revolution, viz.:—that the square of the periodic time varies as the cube of the distance; so that, if the moon moves out further, the month will be longer and the energy of the moon's motion will decrease. The other principle is what is called the law of the consevation of areas or of moment of momentum. Kepler's second law for the motion of planets and comets states that they sweep out equal areas about the centre of attraction in equal times. This second principle is an extension made by Euler to the case where we have any number of bodies moving free from external influence. If we divide them up into equal masses, then the *sum* of all the areas swept out by the radii to each one in a certain time is always the same. Thus in the case of a contracting nebula, when it is very large, the radii out to the masses into which we may suppose it divided are very great, and thus large areas are described with slow rotation. But as it contracts, the radii all shorten, and so the masses must move around faster and faster in order to keep the sum of the areas described the same. Similar reasoning explains why the water in a funnel rotates faster and faster as it comes down to the narrow neck.

These two principles solve our problem. The tides slow up the earth, the masses in the earth describe smaller areas in a certain time, consequently the masses in the moon must describe larger areas. To do this, the moon must move further away, for, remembering the first principle, it could not go faster and stay at the same distance. Stated in a formula, the tides take away moment of momentum of rotation and increase the moment of momentum of the orbital motion of the bodies about each other.

Let us make some applications of the principles just discussed. First, consider the earth-moon system. Looking forwards we see that the moon is gradually getting further away. But let us look backwards. The path is really a spiral winding closer and closer as we look further back. We might think that if we went far enough back we should find the moon in contact with the earth. But such is not the case, we can come very

close, but not to actual contact. The energy is getting greater as we go back, but there is a position in which the energy is a maximum, and the tides could not have produced this condition, for they always decrease the mechanical energy. This critical condition is of great importance for the theory. The surfaces of the earth and moon are then about 4000 miles, or about the radius of the earth apart. They revolve about each other in from two to four hours, always keeping the same face toward each other.

Although we are able to tell quite accurately what this critical state might have been, we are not able to set a rate for the development, for the rate depends on the viscosity at each point in time, and on other factors which we do not know. Tidal friction at present, we have seen, is very small; the estimated 200 million horse-power would take 44 billion years to use up the energy in the earth's rotation. But it is not likely that this was always the case. Geologists demand, at least 100 million years for the geological processes to have taken place. Looking much before that, on the old ideas we find the earth hotter and hotter, then molten. The tides in the viscous earth would be much more effective than now; also the tides vary inversely as the cube of the distance, so that it is not necessary to suppose the evolution to have always proceeded as slowly as at the present time. Darwin* gives the following summary of his theory of the development of the moon from the critical configuration:

> The earth was rotating, with a period from two to four hours, about an axis inclined at 11° or 12° to the normal to the ecliptic, and the moon was revolving nearly in contact with the earth, in a circular orbit coincident with the earth's equator, and with a periodic time only slightly exceeding that of the earth's rotation. Then it was proved that the lunar and solar tidal friction would reduce the system from this primitive condition down to the state which now exists by causing a retardation of terrestrial rotation, an increase in lunar period, an increase of obliquity of ecliptic and an increase of eccentricity of lunar orbit. . . . Thus the theory that tidal friction has been the ruling power in the evolution of the earth and the moon completely co-ordinates the present motions of the two bodies and leads us back to an initial state when the moon first had a separate existence as a

* *Scientific Papers*, Vol. II., p. 455.

satellite. The initial configuration of the two bodies is such that we are almost compelled to believe that the moon is a portion of the primitive earth detached by rapid rotation or other means.

Here mathematical reasoning ends and we are out into the region of speculation. Darwin thought of the earth as being formed from a condensing nebula. He suggested that when the earth had contracted so as to be rotating in a period of from three to four hours, it would be almost unstable, and that an exciting cause of a break-up might have been the tides raised by the sun. The natural period of oscillation of the earth in a molten condition is from one and one-half to two hours. If the the earth rotated in from three to four hours, the tides would be equally timed with its natural oscillations, and we would have the phenomenon of resonance. Large oscillations might arise which would disrupt the planet. We must imagine a part to be detached and hurled to a distance, at least, greater than 4000 miles. Then we must suppose the earth to rotate faster than the new-born moon revolves in order that tidal friction should work in the right direction. The tides would then cause our present system to develop.

Darwin also worked out, at this time, the way in which the eccentricity and inclination of a satellite's orbit would vary under the action of the tides. It was necessary to make assumptions as to what viscosity was present in the earth; but, summing up his investigations, Darwin states: "If we postulate a sufficient lapse of time and that there is no resisting matter throughout space, a system would develop from a primitive planet strongly resembling our own." With regard to the eccentricity, he found that, under certain assumptions as to viscosity, if the moon's orbit had any eccentricity to begin with, the effect of the tides would be to make it more elliptic.

Looking forward into the far distant future, we may prophesy what the ultimate fate of our moon will be. The tides will continue to slow up the earth's rotation till the earth turns round in the same time that the moon revolves around the earth. The two would then revolve about each other, as though connect-

ed by a rigid bar, in 55 of our present days. But this is not the final state, for though the tides due to the moon will have ceased to move over the surface of the earth, yet the tides due to the sun will still be present and will slow up the earth's rotation still more. Then the moon will go around the earth faster than the earth turns on its axis, and the lunar tides will act in a way opposite to that in which they now act. They will hurry up the earth, making the moon move faster and at the same time come closer. This will continue till the moon ultimately falls into the earth, from which it originally started. Even if the time required for our development thus far is hundreds of millions of years, yet it is a short time compared with the great extent required for this future development.

Let us now turn to see if tidal forces have been at work in other parts of the universe. It might, perhaps, be thought that the planets could have broken off from the sun and wound out in spiral paths to their present position. But the planets are comparatively so small and so far away that the tides they raise in the sun can have had no influence on their development. As Sir Robert Ball* said : "The nebular origin of the sun and planets sculptured out the main features of our system, tidal evolution has merely come into play as a subsidiary agent, by which a detail here or a feature there has been chiselled into perfect form." For instance, the observed fact that Mercury and Venus always turn the same side to the sun is easily explained by supposing tidal friction to have stopped their rotation. Japetus, the eighth satellite of Saturn, always presents the same face to the planet, just as our moon keeps the same side toward the earth. Mars rotates more slowly than its nearest satellite Phobos revolves. This moon is too small to have any tidal effect on Mars, so we may explain the rapid revolution by supposing the sun to have slowed up Mars till it rotated more slowly than the moon revolved. We may apply the same reasoning to the inner edge of Saturn's ring, which revolves faster than the planet

**Time and Tide*, page 182.

rotates. Professor Moulton,* however, has pointed out that the tides do not remove all the difficulty in the Laplacian idea that the planet was once a regular nebula extending out to the satellite.

Darwin also suggested a reason for the earth having a special type of moon; for our moon is relatively large compared with the planet and the only one that could have separated from the planet under the influence of tidal friction. On the nebular hypothesis the moons are formed from the mass which is contracting to form a planet, by part being detached under the rapid rotation. What would be the effect of the tides raised in these contracting planets by the future sun? Those far out would be only slightly retarded and so we should expect many moons. The retarding influence would be greater in the case of Mars; thus, the nebula might contract very much before the speed would make the casting-off of a moon necessary. As you remember, Mars has two very small satellites which revolve very close to the planet. Next comes the earth. Within the earth's orbit, Venus and Mercury have no satellites and present the same face to the sun. The earth in its cooling should have been retarded more than Mars and the birth of a satellite still further delayed. This fits in well with the development which Darwin imagined. The earth, perhaps, became almost fluid before its rapid rotation, combined with the disturbance of the solar tides, caused it to form a moon. In this instance, quite a large body was separated in accordance with the laws that govern the break-up of a rotating mass of liquid, not a stray wisp of nebulous matter. Then the reaction of the tides raised in these two would cause our present system to develop.

It is impossible for us to consider all the objections that have been urged against Darwin's theory as applied to our moon, but we may consider one before we turn to double stars. We might note that nearly all the objections have to do with the initial separation of our moon. We have to get it started, in some way, 4000 miles from the surface of the earth, and there is a gap left

* *Astrophysical Journal*, Vol. XI., 1900, p. 109.

in the development, for we cannot trace mathematically the way in which a planet would break up. You all, probably, remember how a Frenchman named Roche gave the explanation for Saturn's rings by showing that, when a small body revolves near a planet, it is torn to pieces by the tidal strains induced in it by the planet. The least distance a small moon can come to a planet and not be broken up is 2·44 times the planet's radius. Now the moon, when we start it, is within this limit and so should be broken up and scattered. But we must remember that Roche's investigation applies only to small moons and ours is a very large one. Darwin* showed in 1887 that the moon would not be broken up till it came within 380 miles of the earth's surface. Jeans has also shown that if the moon were $\frac{1}{10}$th the mass of its primary it could come to actual contact without being broken up.

Let us now consider a striking development of the subject, which brought it into great prominance about the year 1896. Darwin's investigations showed that the effect of the tidal reaction was to make the orbit of the body affected more elliptical, and that the effect was much greater when the two bodies were nearly equal in size. At that time Dr. T. J. J. See computed the orbits of about forty visual double stars and found that they went round each other in orbits that were much more elliptic than the orbits of the planets, in fact having about twelve times the eccentricity. Dr. See applied to them the results of the theory of tidal action worked out by Darwin. He wrote at that time :†

> How then did the double stars originate? By the break-up of a Laplacian ring? Certainly not. . . . . In my earliest essay, before I was acquainted with the researches of Darwin and Poincare on rotating masses of fluid, I suspected that the double stars arose from double nebulæ by a division into two nearly equal masses. As soon as I ascertained from the papers of Darwin and Poincaré that such a division was theoretically possible, I no longer hesitated to affirm that if their results were inapplicable in the solar system, they were of the widest application among the stars, and this conviction was made a certainty when I found from the drawings of Sir John Herschel that double nebulæ exactly resembling the figures computed by the mathematicians actually exist in the heavens.

**Collected Papers*, Vol. III., p. 172.

†*Atlantic Monthly*, October, 1897.

Darwin and Poincaré had looked for application of their results in the solar system; but it was only among the stars and nebulæ of remote space, with the details of which neither was acquainted, that the real discovery was to be made; and it was only possible to one who held in mind the results of mathematical analysis on the one hand and those of Herschel's observations on the other. We may conclude then that the nebulæ divide into two nearly equal parts by a process externally resembling "fission" among the protozoa. When the rotating mass has thus divided into two nearly equal parts, each part will begin to rotate on its own axis, and the tides raised in either mass by the attraction of the other will cause the orbit to grow gradually larger as well as more eccentric; and, in the course of some millions of years, we shall have a double star such as Alpha Centauri.

Since that time new methods have been perfected for discovering double stars. If we observe the spectrum of a double star we notice shifts in the lines due to a component alternately coming towards and receding from us, as it goes around its companion. In this way very close double stars have been found, stars rotating around each other much too close to be seen as double in the largest telescopes. Also these spectroscopic double stars have been found to be remarkably common; thus Campbell and Curtis found that one in seven of the stars they studied was a binary, while Frost and Adams found that for stars of the Orion type the ratio was one in three. Within the past year the theory that tidal influence has been an important factor in their formation has received a strong confirmation. If this theory is true, we should expect the effects of tidal friction to show themselves most strongly in old systems. Now we can arrange the stars in their order of development by means of their spectrum. A certain type of spectrum goes with a star that is far advanced in its development, while another type goes with young hot stars. Thus in old type stars which presumably have been long subject to tidal forces, we should expect to find the components more widely separated with longer periods of revolutions; also, they should have very elliptic paths about each other. This has been confirmed recently by Professor W. W. Campbell,* who concludes: "The orbits of about 70 spectroscopic binary systems

*See this JOURNAL, Vol. IV., No. 5, p. 353.

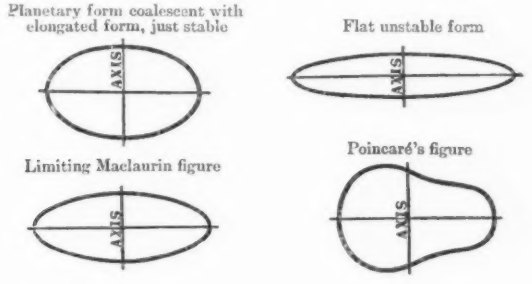
known to date with reasonable accuracy afford confirmation to the theoretical conclusions of Darwin, Poincaré and See, as to the origin and development of stellar systems."

Professor Moulton* has pointed out that visual binaries must have divided when still in the nebulous state. He also shows that if a star in the liquid state separates into two equal parts, the two parts can never become very distant from each other. We have seen that the tides enlarge the orbit, drawing on the rotational momentum. Our moon was so small that it can be forced off to about 70 times the earth's radius; but if the two bodies are equal in mass, the orbital momentum very soon uses up the rotational. It is impossible to consider other possible objections, but we should remember that, apart from gravitation, tidal forces are the only means we at present know by which one star can exert an influence on a companion star. In spectroscopic binaries which are very close and have periods ranging from one and one-half days to three years, these forces must be very great. Thus Darwin's theory will likely be of great importance in fields not at first suspected.

As a last development due to the theory, let us very briefly consider the conditions under which a rotating mass of liquid would break up. This is a fundamental question for Darwin's theory of the origin of the moon and is also suggestive in Laplace's Nebular Theory. Darwin turned his attention to this subject in the 1880's, and in 1885 Poincaré published a masterly paper on the subject. We have seen that if a homogeneous mass of rotating liquid contracts, it must rotate faster, and we might suppose that this increased rotation would cause the mass to become flatter, till finally a ring would separate around the edge. But such is not likely the case. As the mass contracts it will rotate faster and flatten up to a certain stage. These flattened orange-shaped figures are called Maclaurin's spheroids. Up to this stage the figure is stable, that is, if it is disturbed slightly it will come back to its original form; but we must remember that if it is treated very roughly it will break up.

**Publications* of the Carnegie Institution, No. 107, p. 106.

At this stage the liquid has two roads open to it. As it contracts further it may theoretically take one path and become flatter still up to a certain point where it breaks up in a way we cannot trace. All along this path it is unstable; that is, if the smallest disturbance is given to it, it will change its shape entirely. But there is another path it may take. Instead of performing the above balancing feat, it may remain stable under further contraction by changing its shape into an ellipsoid. That is, it will begin to lengthen and have three unequal axis. These figures are called Jacobi's ellipsoids. In these forms the liquid will really not need to rotate so fast as in the previous forms to keep the moment of momentum constant. As the mass contracts still more, the ellipsoid lengthens and tends to become a cigar-shaped figure. At a certain place, however, this form becomes unstable; that is, it would be liable to change on the slightest disturbance. Professor Moulton has calculated that this occurs when the mass is about four and one-half times as dense as when the Jacobian



FIGURES OF EQUILIBRIUM OF A ROTATING BODY
(From Darwin's "The Tides," p. 325).

ellipsoids begin to form. At this stage we have a new series of figures starting, called Poincaré's figures, which are pear-shaped. It is still a question whether these pear-shaped figures are stable or not, but Darwin concluded that they are, although another investigator arrived at the opposite conclusion. As the mass contracts still more, we can only conjecture what happens;

perhaps the neck of the pear grows thinner and finally a mass is detached.

We might say at first that the contracting earth went through the series of forms we have traced and that the end of Poincaré's pear was bitten off and formed the moon. But it is possible to find the momentum corresponding to each figure, and, as we know the momentum of the earth-moon system now, we can find the figure of equilibrium suitable to this when the earth and moon were all in one molten mass. This has been worked out recently by Moulton,* and he finds the surprising result that, in the original state, the earth could not have been rotating nearly fast enough to become as flat as an unstable form. He finds that it would not have been so flat as Saturn is now, in fact, that it would need to have contracted to one-half the present size of the earth before it became as flattened as Saturn.

This is apparently a death-blow to the moon part of the theory. But it is not so conclusive as it at first sight appears. We do not know how stable the Maclaurin spheroids are before they arrive at the unstable form where the slightest disturbance is sufficient to cause them to change; and we must remember that the earth would be subject to disturbances from the sun's tides, especially if, as Darwin suggested, they came to be in resonance with the natural oscillations of the mass. The whole subject of the breaking up of a fluid is still incomplete and indefinite, and it is quite legitimate to accept the break-up and development suggested by Darwin.

These figures of equilibrium are also suggestive in the break-up of a nebula; but we must remember that there are great differences, for Jeans† has shown recently that a uniform nebula is itself unstable, that if a denser part forms, it will precipitate a condensation; also a meteorite passing through a nebula would cause a nucleus to form. Jeans also has made an interesting suggestion as to the figure of the earth. He supposes that the earth is really one of the pear-shaped figures of equilibrium, that

* *Publications* of the Carnegie Institution, No. 107, p. 150.

† *Phil. Trans.*, Vol. CXCIX. A., p. 1; *Ibid.*, Vol. CCI. A., p. 157.

the bottom of the pear forms the "land-hemisphere" and that the top, which has caved in, forms the "water-hemisphere."

Many objections have been raised, especially to the moon part of the theory, which we must pass over, but we can see the general character of these objections. They do not question the existence of the tidal effects but whether they are to be regarded of great or small importance in the development of systems. Thus the tidal Theory does not depend for its importance on any general hypothesis of evolution; for, besides gravitation, tidal influence is the only action by which one celestial body is known to disturb another. In conclusion, we might quote the words of Darwin, who is of a type of scientific man that we may trust to give a fair opinion of his own work. Writing in 1908 he said: "To me it seems that the theory has rather gained than lost in the last twenty-five years, and I observe that several writers are disposed to accept it as an established acquisition to our knowledge of cosmogony."

THE ORBIT OF σ GEMINORUM

By W. E. Harper

THIS star, $\alpha = 7^h\ 37^m{\cdot}0$, $\delta = +29^\circ\ 07'$, photographic magnitude 5·4, was announced * as a spectroscopic binary by Reese in 1903. The four measures given about cover the total range in its velocity.

During 1907, 1910 and the present year thirty-eight spectrograms of this star have been obtained. Numbers 628 and 654 were made on Seed 27 plates using the Universal Spectroscope, dispersion at H_γ 18·6 tenth-metres per millimetre ; numbers 3182 and 3237 on Sigma plates with a three-prism of the same dispersion ; while numbers 3286, 3309 and 3335 were made on Sigma plates with three-prism dispersion of 20·2 tenth-metres per millimetre. The remaining plates were made on Seed 27 emulsion with the single-prism instrument having a dispersion at the same region of 33·4 tenth-metres per millimetre.

The spectrum is of K' type and should yield measurements with a small probable error. The probable error of a plate of $\pm$ 2·17 km. per sec. obtained from our observations is larger than one should expect for a star of this type, but there are many ways in which this may be accounted for. The use of the coarse-grained plates when three-prism dispersion was used, made necessary from the faintness of the star ; the low dispersion for the great majority of the spectrograms, with consequent blending of the spectral lines, and the fact that none of the plates, however poor, have been rejected, may be given as possible reasons for the large probable error of an observation. Reese's comment upon the spectrum, in announcing it as a binary, was : " Numerous lines, hazy yet trustworthy."

An attempt was made to measure the plates on the spectrocomparator, which, in the case of stars having many spectral lines,

* *Lick Observatory Bulletin*, Vol. II., p. 31, 1903.

is faster and regarded as more satisfactory than the ordinary method. However, from lack of intensity of the negatives and consequent diffuseness of the lines, the writer abandoned this in favor of the ordinary method.

The following table contains the data of the measures. The phases are reckoned from periastron passage J. D. 2415824·019 using the period 19·605 which seemed to suit all observations best. The residuals in the last column are scaled from the curve representing the final elements.

MEASURES OF σ GEMINORUM

Plate	Julian Date	Phase	Velocity	Weight	O − C
628	2417629.667	1·988	+ 78·9	9	1·5
654	7043·586	15·907	33·0	9	7·2
3182	8713·667	7·713	32·7	9	+ 0·1
3237	728·673	3·114	72·3	6	3·7
3286	736·673	11·114	8·0	4	− 4·4
3309	741·664	16·105	42·0	9	− 0·5
3335	8748·605	3·441	74·8	9	+ 0·5
3976	9067·753	8·909	18·1	5	− 4·4
3998	083·785	5·336	56·0	7	− 1·5
4022	095·671	17·222	59·0	4	+ 4·0
4032	096·633	18·184	67·3	7	+ 2·6
4047	099·517	1·463	76·8	5	3·8
4055	100·518	2.464	74·1	6	− 5·1
4070	103·680	5·626	55·5	6	+ 1·0
4080	104·719	6·665	49·3	6	+ 6·0
4089	106·641	8·587	27·7	8	+ 2·7
4102	109·669	11·615	16·5	7	+ 4·0
4128	110·668	12·614	9·0	6	− 5·5
4120	112·687	14·633	28·3	8	+ 0·8
4134	116·631	18·577	68·6	8	+ 0·1
4137	120·642	2·983	79·6	8	+ 2·6
4144	124·719	7·060	35·6	5	− 3·4
4155	129·709	12·050	12·0	6	− 0·7
4162	130·700	13·041	18·6	7	+ 2·3
4173	136·670	19·011	70·7	7	− 1·6
4177	137·597	·333	83·8	8	+ 6·0
4186	138·590	1·326	80·6	8	0·0
4196	141·619	4·355	67·6	7	+ 0·4
4202	145·593	8·329	27·6	5	+ 0·6
4211	146·568	9·304	21·0	8	+ 1·5
4221	147·630	10·366	8·8	3	− 5·2
4228	148·599	11·335	9·9	6	− 2·4
4247	151·597	14·333	25·3	6	+ 0·3
4253	152·548	15.284	31·1	7	− 2·7
4263	153·609	16·345	46·8	5	+ 1·4
4271	155·552	18·288	69·7	4	+ 4·0
4280	160·566	3·697	73·4	5	+ 0·9
4293	9161·555	4·686	+ 68·2	7	+ 4·2

For convenience of reference the Lick observations are given here.

OBSERVATIONS AT LICK OBSERVATORY

Date			Julian Date	Phase	Velocity	Residual from O − C
1902	March	16	2415825·7*	1·7	+ 74·	− 6·
1903	January	12	6127·7	9·6	12·	− 5·
	"	13	6128·7	10·6	9·	4·
	February	15	6161·7	4·4	+ 69·	+ 2·

* The decimal of a day is assumed.

A slight increase in the period with the introduction of a correction for possible systematic differences in the measures would cause the residuals from the curve to become very much smaller, but the increase of period would affect our second observation making the residual, already large, much greater. Hence the period decided upon, 19·605 days, was an attempt to equalize these discrepancies.

With this period the observations were grouped, according to phase, into sixteen normal places, and weights assigned to the groups which were in general the sums of the weights of the individual plates.

NORMAL PLACES

	Mean Phase	Mean Vel.	Wt.	O − C		Mean Phase	Mean Vel.	Wt.	O − C
1	1·379	+ 79·14	1·5	− 1·45	9	10·381	+ 13·01	2·5	− ·61
2	2·457	77·90	2·5	− 1·23	10	12·068	12·71	2·0	− ·05
3	3·407	73·70	2·0	− ·75	11	13·637	21·70	1·5	+ 2·00
4	4·521	67·90	1·5	+ 2·19	12	14·930	29·61	1·5	− ·80
5	5·470	55·77	1·5	·60	13	16·006	37·50	1·5	− 4·10
6	6·844	43·07	1·0	+ 1·34	14	16·735	52·22	1·0	+ 2·40
7	7·933	30·88	1·5	+ ·12	15	18·370	68·35	2·0	+ 1·51
8	8·711	+ 24·01	1·5	+ ·02	16	19·505	− 77·69	1·5	+ 2·12

The observations are well represented by a sine curve; the eccentricity is so small that it cannot be differentiated from zero by graphical methods, hence the values of T and ω are indeterminate in this way. Recourse was had to the method of least squares for finding the most probable values of the elements. Since the number of unknowns remained constant it was assumed that the elements which gave the least value for Σpvv would be

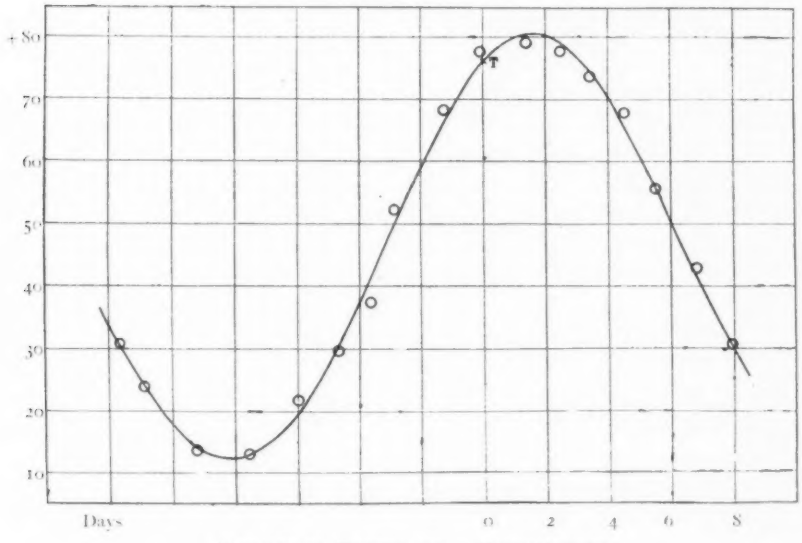
the most probable. Several solutions were made using the following preliminary values:

P = 19·605 days	Preliminary Elements
e = 0·	
ω = 270°, 330°, 360°	
T = J. D. 2415820·752 . . 4·019 . . 5·653	
K = 33·75 km.	
γ = + 45·75 km.	

A value of ω = 190° gave e negative. The following table shows the main result of the solutions. For a circular orbit Σpvv = 79·1.

ω	δe	Σpvv
270°	·022	70·5
330°	·022	68·6
360°	·012	73·8

The values of the other elements varied but little in each solution. In none of the solutions did the residuals as obtained



VELOCITY CURVE OF σ GEMINORUM

by computing directly and by substituting in the observation equations differ more than ·05 km. Though there is little to choose between the various cases it was decided to accept that one for which ω was equal to 330° as a preliminary value. The resulting values of the elements with their probable errors are, then, as follows:

P	= 19·605 days	Final Values
e	= ·022 ± ·018	
ω	= 330° 15′ ± 1° 03′	
K'	= 34·21 km. ± ·58 km.	
γ	= + 45·80 km. ± ·42 km.	
T	= J. D. 2415824·019	
A	= 34·86 km.	
B	= 33·56 km.	
$a \sin i$	= 9,220,400 km.	

The curve shown represents these final values.

Valuable suggestions by the Director, Dr. W. F. King, in the course of this work are hereby gratefully acknowledged.

Dominion Observatory,
Ottawa, Canada,
June, 1911.

STEREOGRAPHIC PROJECTION TABLES

By Otto Klotz

IN connection with my paper "Earthquake Epicentres" of March 6, 1910, published in the Journal of the Royal Astronomical Society of Canada, Vol. IV., No. 3, the following table is published to facilitate the plotting of the necessary lines for determining the position of epicentre. We may recapitulate a few salient points;

$$d = \frac{\cos \phi}{\sin \phi + \cos \Delta'} \qquad r = \frac{\sin \Delta}{\sin \phi + \cos \Delta'}$$

in which Δ = arcual distance (kilometres expressed in degrees) of the epicentre from the respective earthquake station. Δ is obtained from the time interval S–P, the first and second preliminary tremors, and is given for every second of time in Professor Zeissig's table, based on Zöppritz's velocity curves, up to $12^m\ 56^s$, representing 13,000 kms. d = distance from centre of circle, or plane on which projection is made, to the respective stations, and is expressed in units of radius of circle of 1000. r = radius of circle, in same units as above, described from stations as located by d, and on which the epicentre lies. ϕ = latitude of station. The *modus operandi* is simple. We are supposed to be in possession of at least three Δ's for a determinate solution. Preferably the stations selected should differ considerably in longitude. Draw radiating lines representing the respective meridians of the stations, that is, their longitudes. On each lay off its respective d; from the point thus found, describe an arc with radius r. Where the arcs intersect is the epicentre. Its geographic co-ordinates are readily found. The line drawn from the centre of the original circle to the epicentre gives immediately the longitude of the latter; and its distance from the same centre is equal to tan ½ $(90° - \phi_o)$, where ϕ_o is the

latitude of the epicentre. I have been using since the beginning of 1910 printed forms, something like a protractor, of radius 10 cm., and graduated both ways, in half-degrees, from 0°, representing Greenwich, to 180°, so that east and west longitudes can readily be laid off. With the help of the accompanying table an epicentre can be located in a very few minutes from any three of the 27 stations given.

As the distances for Δ are given at 250 km. intervals, it is very simple to interpolate directly for any intermediate value, except for very large values of d and r. The laying-off of the respective meridians, as well as of d and r, should be done with all the accuracy permissible. It may be observed that when $\sin \phi + \cos \Delta$ becomes very small, then d and r become very large, too large for practical application in plotting. For this reason these values are omitted from the table. They are inherent for southern latitudes, as our assumed point of projection is the south pole. The case would be the reverse if we were to project from the north pole. When Δ (in arc) is in the second quadrant, its cosine is negative, so that we may obtain d negative. In this case d is plotted in the opposite direction from the centre along the longitude line produced through the centre, *i. e.*, backwards. The values of d and r were obtained by taking the natural trigonometric functions of ϕ and Δ to four significant figures, and then grinding out the divisions in a "Millionaire" machine. The resulting values are sufficiently accurate for plotting.

Distance	Aachen $\varphi = 50^\circ 46'$ $\lambda = 6^\circ 05'$ E.		Albany $\varphi = 42^\circ 39'$ $\lambda = 73^\circ 45'$ W.		Batavia $\varphi = 6^\circ 11'$ S. $\lambda = 106^\circ 50'$ E.	
Δ in km.	d	r	d	r	d	r
1000	359	89	442	94	1130	178
1250	360	111	444	118	1139	223
1500	362	134	446	141	1150	270
1750	364	156	448	165	1163	318
2000	367	179	452	190	1179	366
2250	369	202	455	214	1197	417
2500	372	225	459	239	1218	469
2750	376	249	464	264	1242	523
3000	380	273	469	289	1269	580
3250	384	297	475	315	1300	639
3500	389	321	481	341	1335	701
3750	394	346	487	368	1374	768
4000	399	371	495	395	1418	838
4250	405	397	503	423	1467	914
4500	412	423	512	452	1523	995
4750	419	450	521	481	1587	1083
5000	426	477	531	511	1659	1180
5250	435	505	542	541	1741	1286
5500	444	534	554	573	1835	1404
5750	454	563	567	606	1944	1536
6000	464	594	581	639	2071	1685
6250	475	625	596	674	2220	1857
6500	488	657	613	710	2397	2055
6750	501	691	631	748	2610	2291
7000	515	725	650	787	2871	2573
7250	530	761	671	828	3197	2920
7500	546	798	694	871	3616	3360
7750	564	837	719	917	4170	3935
8000	584	878	746	964	4939	4725
8250	605	920	775	1014		
8500	627	965	807	1067		
8750	652	1011	843	1124		
9000	679	1061	882	1184		
9250	709	1113	925	1249		
9500	741	1169	973	1319		
9750	777	1228	1026	1394		
10000	817	1291	1086	1476		
10250	860	1359	1152	1566		
10500	909	1433	1228	1664		
10750	963	1511	1313	1773		
11000	1023	1598	1411	1895		
11250	1091	1692	1525	2033		
11500	1169	1797	1656	2190		
11750	1257	1913	1811	2370		
12000	1358	2043	1996	2581		
12250	1476	2189	2219	2831		
12500	1614	2357	2495	3134		
12750	1777	2552	2842	3509		
13000	1973	2779	3291	3987		

Distance	Belgrade $\varphi = 44^\circ 49'$ $\lambda = 20^\circ 27'$ E.		Cartuja $\varphi = 37^\circ 11'$ $\lambda = 3^\circ 36'$ W.		Cleveland $\varphi = 41^\circ 29'$ $\lambda = 81^\circ 42'$ W.	
Δ in km.	d	r	d	r	d	r
1000	419	92	500	98	454	95
1250	421	116	503	123	456	119
1500	423	139	505	148	458	143
1750	425	163	508	173	461	167
2000	428	187	512	199	464	192
2250	432	211	516	224	468	216
2500	436	235	521	250	472	241
2750	440	260	527	277	477	267
3000	445	284	533	304	482	292
3250	450	310	539	331	488	318
3500	455	335	547	359	494	345
3750	462	362	555	387	501	372
4000	469	388	564	416	509	399
4250	476	415	573	445	517	428
4500	484	443	584	476	526	456
4750	493	472	595	507	536	486
5000	502	501	607	539	547	516
5250	513	531	621	572	558	547
5500	524	561	635	606	571	580
5750	536	593	651	642	585	613
6000	549	626	668	679	599	647
6250	563	660	687	717	615	683
6500	578	695	707	757	632	720
6750	594	731	729	798	651	758
7000	612	769	753	842	671	798
7250	631	808	779	888	693	840
7500	652	850	807	936	717	884
7750	675	893	838	987	743	930
8000	700	938	872	1041	771	979
8250	727	986	909	1098	801	1030
8500	756	1036	951	1161	836	1086
8750	788	1090	996	1227	874	1144
9000	824	1147	1047	1298	915	1206
9250	863	1208	1104	1376	961	1273
9500	906	1273	1167	1460	1011	1340
9750	953	1343	1238	1552	1068	1424
10000	1006	1419	1318	1654	1131	1510
10250	1066	1501	1410	1768	1202	1604
10500	1133	1592	1515	1896	1283	1707
10750	1208	1691	1636	2040	1375	1822
11000	1294	1801	1778	2205	1480	1952
11250	1392	1924	1946	2396	1603	2099
11500	1505	2063	2147	2621	1746	2267
11750	1637	2221	2392	2890	1916	2462
12000	1792	2403	2697	3220	2120	2691
12250	1978	2616	3084	3632	2368	2966
12500	2202	2868	3594	4167	2678	3303
12750	2479	3174	4290	4890	3074	3726
13000	2828	3553	5297	5924	3595	4275

Distance	Göttingen $\varphi = 51^\circ 33'$ $\lambda = 9^\circ 58'$ E.		Hamburg $\varphi = 53^\circ 34'$ $\lambda = 9^\circ 59'$ E.		Harvard $\varphi = 42^\circ 23'$ $\lambda = 71^\circ 07'$ W.	
Δ in km.	d	r	d	r	d	r
1000	351	88	331	87	445	94
1250	352	111	333	109	446	118
1500	354	133	334	131	449	142
1750	356	155	336	154	451	166
2000	359	178	338	176	455	190
2250	361	201	341	199	458	215
2500	364	224	344	221	462	239
2750	368	248	347	244	467	265
3000	371	271	350	268	472	290
3250	376	295	354	291	478	316
3500	380	319	358	315	484	342
3750	385	344	363	340	491	369
4000	391	369	368	364	498	396
4250	396	395	374	389	506	424
4500	403	421	380	415	515	453
4750	410	447	386	441	524	482
5000	417	474	393	468	535	512
5250	425	502	400	495	546	543
5500	434	531	408	523	558	574
5750	443	560	417	552	571	607
6000	453	590	427	581	585	641
6250	464	621	437	611	601	676
6500	476	653	448	643	617	713
6750	489	686	459	675	635	750
7000	503	720	472	708	655	790
7250	517	756	486	742	676	831
7500	533	792	500	778	699	874
7750	551	831	516	815	724	920
8000	569	871	533	854	751	967
8250	590	913	551	894	781	1018
8500	612	956	572	937	815	1073
8750	636	1003	594	981	850	1128
9000	662	1051	618	1028	889	1189
9250	690	1103	644	1077	933	1255
9500	722	1157	673	1129	982	1325
9750	756	1215	704	1184	1035	1401
10000	794	1277	738	1243	1096	1483
10250	836	1343	776	1306	1164	1574
10500	882	1415	818	1373	1240	1674
10750	934	1492	864	1445	1327	1784
11000	992	1576	916	1524	1427	1908
11250	1057	1668	975	1609	1542	2048
11500	1131	1769	1040	1703	1676	2206
11750	1215	1881	1114	1805	1834	2390
12000	1311	2006	1199	1919	2023	2605
12250	1423	2146	1296	2047	2252	2860
12500	1553	2307	1408	2190	2535	3171
12750	1706	2491	1539	2354	2892	3556
13000	1889	2707	1694	2542	3356	4048

Distance	Helwan $\varphi = 29^\circ 52'$ $\lambda = 31^\circ 21'$ E.		Jugenheim $\varphi = 49^\circ 46'$ $\lambda = 8^\circ 39'$ E.		Königstuhl $\varphi = 49^\circ 25'$ $\lambda = 8^\circ 42'$ E.	
Δ in km.	d	r	d	r	d	r
1000	584	105	369	89	372	90
1250	586	132	370	112	374	112
1500	590	159	372	134	376	135
1750	594	186	374	157	377	158
2000	598	213	377	180	380	181
2250	604	241	380	203	383	204
2500	610	269	383	227	386	227
2750	617	298	386	250	390	251
3000	624	327	390	274	394	275
3250	633	357	395	299	399	299
3500	642	387	400	323	404	324
3750	652	418	405	348	409	349
4000	664	450	411	374	415	375
4250	676	482	417	400	421	401
4500	689	516	424	426	428	427
4750	704	551	431	453	436	454
5000	720	587	439	481	443	482
5250	737	624	448	509	452	511
5500	756	663	457	538	462	540
5750	776	703	467	568	472	570
6000	799	745	478	599	483	600
6250	823	789	490	630	495	632
6500	850	835	502	663	507	665
6750	879	884	516	697	521	699
7000	911	936	531	732	536	734
7250	946	991	546	768	552	771
7500	985	1049	564	806	569	809
7750	1027	1111	582	846	588	849
8000	1075	1179	602	887	609	890
8250	1127	1251	624	930	631	934
8500	1186	1330	648	975	655	979
8750	1251	1415	674	1023	682	1027
9000	1325	1509	702	1074	710	1078
9250	1409	1613	733	1127	742	1132
9500	1504	1729	767	1184	776	1190
9750	1614	1860	805	1245	814	1251
10000	1741	2008	846	1309	857	1317
10250	1891	2178	892	1380	903	1387
10500	2067	2377	943	1455	955	1464
10750	2279	2610	1000	1538	1013	1547
11000	2539	2891	1064	1627	1079	1638
11250	2863	3238	1137	1726	1153	1738
11500	3277	3675	1219	1835	1236	1848
11750	3827	4248	1313	1950	1333	1972
12000	4588	5032	1421	2093	1444	2111
12250	- -	- -	1548	2248	1574	2269
12500	- -	- -	1697	2427	1727	2452
12750	- -	- -	1874	2634	1909	2665
13000	- -	- -	2088	2880	2130	2917

Distance	Laibach $\varphi = 46^\circ\ 03'$ $\lambda = 14^\circ\ 31'$ E.		Manila $\varphi = 14^\circ\ 35'$ $\lambda = 120^\circ\ 59'$ E.		München $\varphi = 48^\circ\ 09'$ $\lambda = 11^\circ\ 37'$ E.	
$\perp$ in km.	d	r	d	r	d	r
1000	406	92	781	126	385	90
1250	408	115	785	158	387	113
1500	410	138	791	191	389	136
1750	413	161	797	224	391	159
2000	415	185	805	257	393	182
2250	419	209	813	291	396	206
2500	422	233	823	326	400	229
2750	426	257	834	361	404	253
3000	431	282	847	397	408	278
3250	436	307	861	435	412	302
3500	441	332	876	473	418	327
3750	447	358	893	513	423	352
4000	454	384	912	554	429	378
4250	461	411	933	597	436	405
4500	469	439	956	642	443	431
4750	477	467	981	688	451	459
5000	486	496	1009	737	459	487
5250	496	525	1040	789	468	516
5500	507	555	1074	844	478	545
5750	518	586	1111	902	489	576
6000	531	619	1153	964	501	607
6250	544	652	1199	1030	513	639
6500	559	686	1250	1101	526	673
6750	574	722	1307	1178	541	707
7000	591	759	1371	1262	556	743
7250	609	798	1443	1354	573	780
7500	629	838	1525	1456	592	819
7750	651	880	1619	1569	612	860
8000	674	924	1726	1696	633	902
8250	700	971	1850	1840	657	947
8500	728	1020	1995	2004	682	994
8750	758	1072	2166	2195	710	1043
9000	792	1127	2371	2420	740	1096
9250	829	1186	2621	2689	774	1152
9500	869	1249	2930	3018	810	1211
9750	914	1316	3325	3432	851	1274
10000	964	1389	3844	3971	896	1342
10250	1020	1468	- -	- -	946	1416
10500	1082	1554	- -	- -	1001	1496
10750	1152	1649	- -	- -	1063	1583
11000	1231	1753	- -	- -	1134	1678
11250	1322	1869	- -	- -	1214	1784
11500	1427	1999	- -	- -	1304	1901
11750	1547	2146	- -	- -	1409	2033
12000	1688	2315	- -	- -	1531	2182
12250	1857	2510	- -	- -	1673	2353
12500	2058	2740	- -	- -	1842	2551
12750	2304	3015	- -	- -	2045	2784
13000	2610	3351	- -	- -	2294	3063

Distance	Ottawa $\varphi = 45^{\circ}\ 24'$ $\lambda = 75^{\circ}\ 43'$ W.		Pulkowa $\varphi = 59^{\circ}\ 46'$ $\lambda = 30^{\circ}\ 20'$ E.		Samoa (Apia) $\varphi = 13^{\circ}\ 48'$ S. $\lambda = 171^{\circ}\ 45'$ W.	
Δ in km.	d	r	d	r	d	r
1000	413	92	272	84	1296	209
1250	415	115	273	106	1308	263
1500	417	139	274	127	1323	318
1750	419	162	276	149	1341	375
2000	422	186	277	170	1363	434
2250	426	210	279	192	1388	495
2500	429	234	282	214	1417	558
2750	433	258	284	236	1450	625
3000	438	283	287	259	1488	696
3250	443	308	290	281	1532	771
3500	449	334	293	304	1581	851
3750	455	360	297	328	1638	937
4000	462	386	301	351	1702	1030
4250	469	413	305	375	1776	1132
4500	477	441	310	400	1861	1244
4750	486	469	315	425	1959	1369
5000	495	498	320	450	2072	1509
5250	505	528	326	476	2206	1668
5500	516	559	333	502	2363	1850
5750	528	590	340	529	2552	2063
6000	540	622	347	557	2781	2316
6250	554	656	355	586	3063	2622
6500	569	691	363	615	3420	3002
6750	585	727	372	645	3884	3489
7000	602	764	382	676	4507	4135
7250	621	803	393	708		
7500	641	844	404	741		
7750	664	887	416	775		
8000	688	932	429	811		
8250	714	979	443	848		
8500	743	1029	459	886		
8750	774	1081	475	926		
9000	809	1137	493	968		
9250	847	1197	513	1012		
9500	888	1261	534	1058		
9750	935	1330	557	1106		
10000	986	1404	583	1157		
10250	1044	1485	611	1212		
10500	1108	1574	641	1269		
10750	1181	1670	674	1330		
11000	1264	1778	712	1396		
11250	1358	1897	753	1466		
11500	1467	2032	798	1542		
11750	1594	2185	850	1624		
12000	1742	2360	907	1714		
12250	1919	2564	972	1812		
12500	2132	2806	1046	1920		
12750	2394	3096	1131	2039		
13000	2722	3453	1228	2173		

Distance	Seattle $\varphi = 47^\circ\ 39'$ $\lambda = 122^\circ\ 18'$ W.		St. Boniface $\varphi = 49^\circ\ 54'$ $\lambda = 97^\circ\ 07'$ W.		St. Louis $\varphi = 38^\circ\ 38'$ $\lambda = 90^\circ\ 14'$ W.	
Δ in km.	d	r	d	r	d	r
1000	390	91	368	89	485	97
1250	392	113	369	112	487	122
1500	394	136	371	134	489	146
1750	396	160	373	157	492	171
2000	399	183	375	180	496	196
2250	402	206	378	203	500	222
2500	405	230	381	227	505	247
2750	409	254	385	250	510	273
3000	413	279	389	274	516	300
3250	418	303	393	298	522	326
3500	423	328	398	323	529	354
3750	428	354	403	348	537	382
4000	435	380	409	373	545	410
4250	442	406	415	399	554	439
4500	449	433	422	426	564	469
4750	457	461	430	453	575	500
5000	466	489	438	480	587	531
5250	475	519	446	509	599	563
5500	485	548	455	538	613	597
5750	496	578	465	567	628	632
6000	508	610	476	598	645	667
6250	520	642	488	630	662	705
6500	534	676	500	662	681	743
6750	549	711	514	696	702	784
7000	565	747	528	731	724	826
7250	582	784	544	767	749	871
7500	601	824	561	805	776	917
7750	621	865	580	844	805	967
8000	643	908	600	886	837	1019
8250	667	953	622	929	871	1073
8500	693	1000	645	974	911	1134
8750	721	1050	671	1022	953	1197
9000	752	1103	699	1072	1001	1265
9250	787	1159	730	1125	1053	1339
9500	824	1219	764	1182	1112	1418
9750	865	1284	801	1242	1177	1506
10000	912	1353	842	1307	1251	1602
10250	963	1428	888	1377	1335	1708
10500	1019	1509	938	1452	1431	1826
10750	1084	1598	995	1534	1541	1959
11000	1156	1695	1059	1623	1670	2111
11250	1239	1803	1130	1721	1820	2285
11500	1332	1923	1212	1830	1998	2488
11750	1441	2058	1305	1950	2214	2727
12000	1567	2212	1413	2086	2478	3016
12250	1715	2388	1538	2240	2808	3372
12500	1891	2593	1685	2417	3233	3824
12750	2103	2835	1860	2623	3800	4417
13000	2364	3126	2072	2866	4587	5232

Distance	Strassburg $\varphi = 48^\circ\ 35'$ $\lambda = 7^\circ\ 46'$ E.		Sydney $\varphi = 33^\circ\ 50'$ S. $\lambda = 151^\circ\ 10'$ E.		Tashkent $\varphi = 41^\circ\ 20'$ $\lambda = 69^\circ\ 18'$ E.	
Δ in km.	d	t	d	t	d	t
1000	381	90	1928	393	456	95
1250	382	113	1959	460	458	119
1500	384	136	1999	562	460	143
1750	386	158	2048	669	463	167
2000	389	182	2107	784	466	192
2250	392	205	2178	907	470	217
2500	395	229	2263	1042	474	242
2750	399	253	2365	1192	479	267
3000	403	277	2486	1359	484	293
3250	408	301	2631	1548	490	319
3500	413	326	2808	1766	496	345
3750	418	351	3024	2023	503	372
4000	424	377	3294	2331	511	400
4250	431	403	3635	2709	519	428
4500	438	430	4081	3190	529	457
4750	446	457	- -	- -	538	487
5000	454	485	- -	- -	549	517
5250	463	514	- -	- -	561	548
5500	473	543	- -	- -	573	581
5750	483	574	- -	- -	587	614
6000	495	605	- -	- -	602	648
6250	507	637	- -	- -	618	684
6500	520	670	- -	- -	635	721
6750	534	704	- -	- -	654	759
7000	549	740	- -	- -	674	800
7250	566	777	- -	- -	696	842
7500	584	816	- -	- -	720	886
7750	604	856	- -	- -	746	932
8000	625	898	- -	- -	775	981
8250	648	942	- -	- -	805	1032
8500	673	989	- -	- -	840	1088
8750	700	1038	- -	- -	878	1146
9000	730	1090	- -	- -	919	1209
9250	763	1145	- -	- -	965	1277
9500	799	1203	- -	- -	1016	1349
9750	838	1266	- -	- -	1073	1428
10000	882	1333	- -	- -	1137	1514
10250	931	1406	- -	- -	1209	1609
10500	985	1485	- -	- -	1290	1713
10750	1046	1570	- -	- -	1383	1829
11000	1115	1664	- -	- -	1490	1960
11250	1192	1768	- -	- -	1614	2108
11500	1281	1883	- -	- -	1759	2277
11750	1382	2011	- -	- -	1930	2474
12000	1500	2157	- -	- -	2137	2707
12250	1638	2323	- -	- -	2389	2985
12500	1801	2516	- -	- -	2704	3327
12750	1997	2742	- -	- -	3107	3757
13000	2236	3011	- -	- -	3638	4317

Distance	Tiflis $\varphi = 41^\circ 43'$ $\lambda = 44^\circ 48'$ E.		Washington $\varphi = 38^\circ 54'$ $\lambda = 77^\circ 03'$ W.		Wien $\varphi = 48^\circ 15'$ $\lambda = 16^\circ 22'$ E.	
Δ in km.	d	r	d	r	d	r
1000	452	95	482	97	384	90
1250	453	119	484	121	386	113
1500	456	143	486	146	388	136
1750	459	167	489	171	390	159
2000	462	191	493	196	392	182
2250	465	216	497	221	395	205
2500	470	241	501	247	399	229
2750	474	266	506	273	403	253
3000	480	292	512	299	407	277
3250	485	318	519	326	411	302
3500	492	344	526	353	417	327
3750	499	371	533	381	422	352
4000	506	399	542	409	428	378
4250	514	427	551	438	435	404
4500	523	456	560	468	442	431
4750	533	485	571	498	450	459
5000	544	515	583	530	458	487
5250	555	546	595	562	467	515
5500	568	578	609	595	477	545
5750	581	611	624	630	488	575
6000	596	646	640	665	499	606
6250	611	681	657	703	512	639
6500	628	718	676	741	525	672
6750	647	756	697	781	539	707
7000	667	796	719	823	555	742
7250	688	838	743	868	572	780
7500	712	881	770	914	590	818
7750	738	928	799	963	610	859
8000	766	976	831	1015	631	901
8250	796	1026	865	1070	654	946
8500	830	1082	903	1129	680	993
8750	867	1140	945	1192	708	1042
9000	908	1202	992	1259	738	1094
9250	953	1268	1044	1332	771	1150
9500	1003	1340	1101	1411	808	1209
9750	1059	1418	1166	1497	848	1272
10000	1122	1503	1239	1592	893	1340
10250	1192	1596	1322	1697	942	1414
10500	1272	1699	1416	1814	997	1493
10750	1362	1813	1524	1945	1059	1580
11000	1466	1940	1650	2094	1129	1675
11250	1587	2085	1798	2266	1209	1780
11500	1728	2251	1973	2464	1299	1897
11750	1894	2443	2182	2699	1403	2028
12000	2094	2669	2430	2982	1523	2176
12250	2338	2938	2762	3328	1665	2346
12500	2640	3268	3172	3766	1832	2542
12750	3026	3681	3718	4339	2034	2774
13000	3531	4215	4472	5121	2280	3050

DOMINION OBSERVATORY,
OTTAWA, CANADA,
May 1, 1911.

MEETINGS OF THE SOCIETY

At Toronto.

May 2.—In the absence of the President, Professor Chant occupied the chair.

The Librarian reported the receipt of 41 Publications during the month of April—10 from Great Britain, 8 from the United States, 8 from France, Belgium and Canada; from Germany, Spain, etc., 15.

Professor Coleman gave the lecture of the evening on "Points of Contact between Geology and Astronomy." The various theories of the formation of the solar system were discussed and the points wherein they agreed or conflicted with geological facts were pointed out. The question of climate was considered, and the effects upon it of the condition of the atmosphere. It was stated that if carbonic acid gas was more abundant in the atmosphere than at present, such condition would lead to more heat being retained; whilst a diminution of the quantity of carbonic acid gas in the air would lead to a lowering of the temperature. This was a physical explanation of the cause of the ice ages on the earth, which the lecturer favored. The astronomical explanation based upon the precession of the equinoxes the lecturer regarded as insufficient to account for the great changes in the temperature of the earth's surface during geological periods. The theory in regard to the solar system passing through colder or warmer regions in space was mentioned, but regarded as a merely speculative idea.

May 16.—On request, the President of the Society, Professor DeLury, gave a short account of a visit which he had paid to the West. Besides delivering addresses on educational sub-

jects at Saskatoon and Regina, he lectured to the Regina Centre of the Society. He reported a strong and growing interest in astronomy both at Regina and at Winnipeg, where short stops was made.

The paper of the evening was by Mr. A. J. Dempster, M.A., of the University of Toronto, on "Darwin's Tidal Theory." It reviewed the theory as originated by Darwin and showed that the more recent investigations of Chamberlin, Moulton, Poincaré and others have not diminished its importance. A full account of the paper is given in this issue. (See page 185).

May 30.—Mr. W. P. Byrch and Miss Florence Byrch, of 30 Charles St. West, Toronto, were elected members of the Society.

Mr. Tyson drew attention to the fact that the southward motion of Venus was very noticeable at this time. Being near the bright stars Castor and Pollux, the planet's daily movement from these two reference points was quite apparent.

Mr. Elvins reported observing a daylight aurora a few days previously; which appeared as a luminous arc without color.

This was the last indoor meeting of the term until September. An outdoor meeting for observation, with telescopes, on the campus of the University was announced for June 13th or 14th dependent on weather conditions.

The paper of the evening was on "Calendars, Ancient and Modern," by Dr. A. D. Watson. The paper was of unusual interest and was generally discussed by the members. It appears in this issue. (See page 172).

June 14.—The closing meeting of the session was an open-air gathering for observations. Four telescopes were provided, and the large number of visitors were permitted to see Venus, Jupiter, the Ring Nebula, β Cygni, ϵ Lyræ and other interesting objects. The meeting did not break up until after 11 o'clock.

L. G.

At Ottawa

April 20, 3 p.m., at the Observatory.—Mr. J. L. Rannie was elected a member of the Society.

The lecture of the day was by Mr. R. M. Stewart, M A., on the " Principle of Relativity."

Mr. Stewart first gave in outline the theories in relation to the propagation of light, both as to the time of traversing space and as to the manner of its transmission, the latter consideration leading to the invention of the medium *ether*. The wave-theory of transmission becomes complicated when bodies are in motion, and the question as to the motion of bodies relative to the ether or absolute motion at once suggests itself.

Mr. Stewart then explained several attempts to ascertain the absolute motion of bodies. The first was by comparing the aberration of light when a telescope is filled with (1) air (2) water. This experiment did not agree with theory as the results were the same in each case. The assumption that the ether was stationary in and about the telescope was tested experimentally by noting the difference in the deflection of a ray of light through a prism (1) at rest, (2) in motion towards source of light. The result showed no difference and hence the two experiments appeared contradictory.

Fresnel attacked the problem by assuming that the velocity of ether-drift through a body in motion is different from that relative to the body in free space. His formula amounts to the assumption that the refractive index of a substance depends only on the density of the ether within it. By this means he succeeded in reconciling all experimental facts known at that time.

Michelson-Morley outlined a theory as to the times of transmission of light in the direction of motion of the earth and contrary to that direction. The theory indicated that these times should be different, but experiment did not confirm the theory.

Other experiments connected with the same problem were performed by Lodge, Troughton and Noble, the latter men using an electrostatic condenser, thus attacking it in an entirely different way.

The fact that all these attempts to measure absolute motion failed, no matter how varied the experimental means adopted, forced the conclusion that some principle must exist by reason of

which it is impossible to recognise absolute motion. To this we may add the principle (which follows directly from the wave-theory) that the velocity of light is independent of the motion of its source.

From these two principles Mr. Stewart showed that the fundamental units of time, mass and length, which we had formerly considered absolutely fixed, really depend upon the motion of the system considered. Moreover, the unit of length depends upon the direction of motion, *i. e.*, the longitudinal unit differs from the unit transverse to direction of motion.

Finally Mr. Stewart showed how the transformation of Maxwell's electro-magnetic equations to the case of axes in uniform motion leads to the same general conclusions and to the same mathematical equations. This transformation was first developed by Lorenz, and the law of change of mass with velocity was verified experimentally in the case of β particles by Kaufmann.

May 4, 8 p.m., in Y.M.C.A. Hall.—Mr. John A. Paterson, K.C., of Toronto, gave a paper entitled "The Astronomy of Shakespeare." This paper first sketched the astronomical theories and schools of thought before and up to the time of Shakespeare. The Ptolemaic system was still believed in by many of the able scholars of the time, among them being the great philosopher Bacon, so it is little wonder that Shakespeare should also adopt this system. Nevertheless, many passages of his writings show that in some way, whether by intuition or from actual knowledge, Shakespeare has hinted at many things which have since been proven to be actual facts.

Mr. Paterson's lecture abounded in quotations from the author to illustrate the points discussed. The lecture was much enjoyed by those present and a hearty vote of thanks was tendered to Mr. Paterson.

May 23, 3 p.m., at the Observatory.—Messrs. J. F. Fredette and G. H. Herriot, both of the Topographical Surveys Branch, Department of the Interior, Ottawa, were nominated for membership in the Society.

Two papers were presented. The first one, entitled "Personal Errors in Meridian Circle Work," was by Mr. D. B. Nugent, M.A., and dealt with the results of transit work at the Observatory during the year 1910.

Mr. Nugent first reviewed briefly the chief points discussed in a former paper by Mr. R. M. Stewart on the personal error of setting micrometer wires on different marks. The paper to-day was the particular case of setting two parallel wires on a moving star. By means of the reversing prism the apparent motion of the star was reversed, and hence the personal error obtained. By means of an elaborate series of results Mr. Nugent showed the values of his own personal error to be zero and that of Mr. Stewart 0″·026 when reduced to the meridian, his settings being in advance of the star in the case of those stars transiting south of the zenith and behind when the transit was north. Mr. Nugent also pointed out that the magnitude of this error expressed in angular measure did not depend, as far as might be deduced from the results shown, on either the magnitude or the declination of the stars observed.

In the discussion following this paper Mr. Stewart pointed out that in the setting of a single wire on a star the personal error did depend on the magnitude of the star; hence the advantage of the two wires in the eyepiece.

The second paper, by R. E. DeLury, Ph.D., was entitled "Errors in the Measurement of Spectral-Line Displacements."

Dr. DeLury stated that investigators were uncertain as to the accuracy of measurements in the third decimal place of an Angstrom unit and quoted results of eminent observers showing that they agreed only up to this point. In determing the rotation of the sun, this uncertainty would give rise to an uncertainty in the velocity of sun's limb amounting to the second decimal place in kilometres per second. At Mount Wilson the value obtained, namely 2·05, would be affected in the second decimal place.

Dr. DeLury suggested that the errors of measurement might be partly due to personal errors analogous to those met with in

transit work. By a specially devised double-slit, plates were taken and comparative measurements were made by Dr. DeLury and Mr. Plaskett of the same line displacements. The comparison showed Mr. Plaskett's measurements to be always larger and the differences, about 0·0004 Angström unit, were sufficient to account for some of the uncertainty referred to above. Systematic errors of measurement occurred in the cases of some lines which, if occurring in an actual plate, would lead us to suppose different rates of rotation for the different elements.

In commenting on this paper Mr. Plaskett said that the great difficulty in the way of further progress lies in the fact that systematic errors and accidental errors are of the same order, and only by eliminating the latter as far as possible and by studying a great many results can we hope to increase our knowledge.

C. E.

At Hamilton

May 12.— Mr. Lachlan Gilchrist, M.A., of the University of Toronto, gave a lecture on "The Habitability of Other Worlds."

In order to prevent wild speculation the lecturer stated that only life similar to that we know would be considered, and that demanded a certain range of temperature, an atmosphere in some measure resembling ours, and the presence of water. Considerations of the densities and cloudy appearances of the major planets precluded them from being the possible abode of life such as ours. On the other hand the probable rotations of Mercury and Venus being identical with their revolution about the sun, meant conditions of temperature incompatible with life.

Thus we were left with our next neighbor Mars. The lecturer then took up the question of ascertaining whether water vapour were present in the atmosphere of Mars. He described two methods by which the absorption spectrum of our atmosphere might be recognised, viz. if observation of the approaching and receding limbs of the sun be observed, lines due to the sun's atmosphere would be shifted to right and left, while any due to

our atmosphere would not; and again if observations be taken when the sun is at a low and then at a high altitude, the difference of the amount of atmosphere travelled through would show in the strengthening of the absorption spectrum.

The question as to the presence of water vapour in the atmosphere of Mars in any considerable quantity was still a matter of controversy, some results seeming to show evidence in favor, while others were decidedly negative.

The lecture was much enjoyed and at the close the speaker was accorded a hearty vote of thanks.

The President of the Centre, after announcing the next lecture, stated that at the close of the course every Monday night the observatory would be open to all members and friends, but should the night prove cloudy the first clear night following would be taken advantage of.

May 26.—Mr. Gerald Nickland, 69 York St., Hamilton, was elected a member of the Society.

Mr. J. E. Maybee, of Toronto, delivered an address entitled "Some Contributions of Astronomy to Human Life and Thought."

We are indebted to astronomy for the final establishment of direction and position upon the earth's surface, which is absolutely a necessity for mariners.

Next, time is determined by astronomy and rapid transit is made possible.

Again, chronology if helped, for many past events can be placed in their proper place in history by reference to some event the date of which is discoverable by astronomy; for example, the landing of Cæsar in Britain has been brought within certain limits by study of the tides.

T. H. W.

At Guelph

April 27, 1911.—Organization Meeting in the Public Library Hall. The following officers were elected :—

Honorary President, Colonel A. H. Macdonald, K.C.
Honorary Vice-President, Dr. W. F. Savage.
President, Henry Westoby, Esq.
1st Vice-President, Professor W. H. Day, B.A.
2nd Vice-President, Dr. J. Lindsay.
Secretary, H. E. S. Asbury.
Recorder, J. T. Luton.
Treasurer, H. J. B. Leadlay.
Council, Dr. A. H. Hobbs, Rev. W. J. Wilson, W. C. McLaren, W. Tytler, Mrs. H. J. B. Leadlay and Mrs. W. O. Stewart.

List of members:—

Dr. E. C. Barnes, W. J. Bell, M. S. Bœhm, W. E. Buckingham, George Chapman, Rev. G. F. Davidson, W. H. Hamilton, J. R. Howitt, M.PP., Norman Macdonald, Dr. H. Howitt, Dr. H. Orton Howitt, C. E. Freer, J. M. Taylor, Dr. H. G. Roberts, Harry Mahoney, Rev. C. A. Sparling, Colonel John Davidson, R. L. Torrance, D. E. Rudd, R. H. Brydon, J. A. Scott, J. J. Whaley, G. Clifton Thompson, Mrs. W. H. Day, J. McNiece, Miss Mary Mills, Lieut.-Col. D. McCrae, J. Hutcheon, E. Robinson, Samuel Terrell, T. J. Colwill, R. W. Wade, J. Price, J. J. Thomas, Dr. H. C. Skinner, J. J. Drew, R. R. Graham, Dr. G. C. Creelman, Dr. W. O. Stewart, Adam Taylor, F. A. Græsser, J. M. Taylor, Jr., J. M. Duff, G. B. Ryan, Dr. Hugh C. McLean, Professor J. B. Reynolds, H. L. Fulmer, Dr. R. Lucy, F. J. Winlow, H. C. Scholfield, J. W. Lyon, Mrs. T. Cæsar, Professor R. Harcourt, Professor S. B. McCready, E. W. Kendall, G. E. Smith, G. P. McKay, L. D. Jackson, Miss E. C. Dwight, Mrs. R. B. Dwight, Miss Beatrice M. Bethune, J. E. Howitt. Dr. A. T. Hobbs, Dr. J. Lindsay, Rev. W. G. Wilson, Colonel A. H. Macdonald, Dr. W. F. Savage, Wm. McLaren, H. E. S. Asbury, Henry Westoby, Professor W. H. Day, William Tytler, H. J. B. Leadlay, Mrs. H. J. B. Leadlay, Mrs. W. O. Stewart, J. T. Luton.

May 8.—An informal meeting was held on the lawn of Mr. Wm. Tytler. Those who were present had the pleasure and profit of viewing the moon, and Jupiter with his satellites through

the telescopes of the President of the Society, Mr. H. Westoby.

May 18.—A meeting of the Society was held in Carnegie Hall. The Honorary-President, Colonel A. H. Macdonald, occupied the chair.

In addition to the foregoing list the following persons were elected members:—G. P. McKay, Jas. Watt, R. H. McPherson, Miss L. M. Rogers, Miss P. J. Ryan, Wm. Laidlaw, Mrs. W. Bell, C. L. Dunbar, Dr. G. B. Tovell, Miss Maud Odroskie, Miss Madge Day, W. P. Gamble, A. C. Brown, Miss J. Davidson, Miss May Day, Rev. G. W. Arnold, Dr. W. H. Lowry, R. S. Cull, Sheriff A. S. Allan, Miss E. Shields, J. Davison.

The most interesting feature of the meeting was an address on "The Solar System," by Prof. A. T. DeLury, of the University of Toronto. Mr. DeLury first outlined the history and work of the Royal Astronomical Society of Canada, then, dealing with his subject he showed how conclusions are reached regarding the movements of the planets, the method of determining distances in the heavens, and how facts were established concerning the satellites. He dealt with facts relating to the sun, its work and rotation, facts relating to the moon and its phases, and the distances of the planets. The presentation of lantern views gave additional interest to the subject.

June 9.—At a meeting of the Society in Carnegie Hall, the following persons were added to the membership:—E. A. Macdonald, E. Barelman, Robt. Mitchell, Mrs. J. J. Drew.

The President, Mr. Westoby, gave a very interesting address on the subject, "The Suns of the Heavens. He showed how the so-called stars are great suns, and dealt with their sizes and distances, making special mention of Canopus and others. The address was illustrated with lantern views of our own.

J. T. L.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

April, 1911

Temperature—The mean temperature of April was below average over the larger part of the Dominion, the Province of Manitoba and the northern and eastern portions of Saskatchewan, together with the district lying between Georgian Bay and the Upper St. Lawrence Valley, alone shewing a positive departure from normal. The largest negative departures, from 4° to 6°, occurred in the Ottawa Valley and in Southern Alberta, while the largest positive departure was at Winnipeg. Comparison of these conditions with those of March shews a continued backwardness in the season from Lake Huron eastward and a continuation of unusual warmth in Manitoba and Eastern Saskatchewan. West of Regina to the Pacific Coast a remarkably warm March was followed by a cold April.

Precipitation—A precipitation slightly in excess of the average was almost general in the Western Provinces and occurred very locally in Ontario, while in other parts of the Dominion there was a deficiency which was quite pronounced throughout the Maritime Provinces and in some districts of Quebec and British Columbia.

May, 1911

Temperature—The mean temperature of May exceeded the normal from Eastern Saskatchewan to the Maritime Provinces, and was below elsewhere in Canada. Very warm weather pre-

vailed in Ontario and Quebec, where departures from average were from 3° to 9°. In the Maritime Provinces the positive departures ranged between 0·5° and 7°. In districts where the normal was not reached the departure was from 0·3° to 4°, the latter difference being in the Cariboo District of British Columbia.

Precipitation—The feature of chief interest with regard to precipitation was a very marked deficiency in the Maritime Provinces, and particularly in the southwestern portion of New Brunswick where the total rainfall was less than one inch. An almost general deficiency also occurred in the Peninsula of Ontario and in the St. Lawrence Valley, the whole month being characterized by fine weather and much bright sunshine. In some localities, however, notably at Kingston, heavy thunderstorms caused an excess of the average. In northwestern Ontario and thence westward to British Columbia, omitting a large part of southwestern Saskatchewan, the precipitation was in excess of the average, the largest positive departures reported being nearly two inches at Qu'Appelle and two and a half inches at Calgary.

R. F. S.

Temperatures for April and May, 1911

Station	April		May	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	58	- 24	66	22
British Columbia				
Atlin	52	12	58	22
Agassiz	75	26		
Barkerville	56	8	78	22
Kamloops	72	20	86	28
New Westminster	73	28	78	36
Prince Rupert	60	20	66	32
Vancouver	66	30	74	38
Victoria	70	28	72	37
Western Provinces				
Battleford	76	4	94	24
Broadview				
Calgary	74	- 13	83	26
Carman			87	20
Edmonton	77	15	83	24
Medicine Hat	80	3	99	30
Minnedosa	80	4	86	13
Moose Jaw	74	5	90	19
Oakbank	78		85	21
Portage la Prairie			84	19
Prince Albert	74	2	90	22
Qu'Appelle	74	- 6	87	20
Regina	70	- 2	88	15
Swift Current	76	2	90	24
Winnipeg	80	5	86	19
Ontario				
Agincourt	79	12	93	26
Aurora	77	11	92	25
Bancroft	77	- 10	92	21
Barrie	75	5		
Beatrice	75	3	88	21
Birnam	72	12	90	27
Bloomfield	73	9	90	28
Brantford	76	14	95	27
Bruce Mines	66	3	82	12
Chatham	74	17	96	28
Clinton	72	7	89	18
Cottam	75	10	95	24
East Toronto	77	11	90	25
Gravenhurst	77	- 4	87	22
Guelph	74	12		
Haliburton	78	4	95	21
Hamilton	76	18	96	30
Huntsville	77	5	90	18
Kenora	70	- 3		
Kinmount	75	- 4	92	21
Kingston	67	10	85	28
Lakefield	71	12	88	25
London	76	14	92	27
Lucknow	75	5	88	21
Madoc	77	7	92	26
Meaford				
Midland	85	15	92	30
North Gower				
Otonabee	74	10	91	27
Ottawa	79	2	90	25
Owen Sound			97	25
Paris	78	15	95	27
Parry Sound	76	9	89	23
Peterboro'	78	5	92	24
Point Clark				
Port Arthur	57	- 2	80	21
Port Burwell	71	15	87	27
Port Dover	70	15	86	25
Port Hope				
Port Stanley	68	16	86	28
Ronville	76	1	86	19
Sarnia	75	15	90	31
Southampton	68	13	90	27
Stonecliffe	75	- 8	92	20
Stony Creek	78	17	95	30
Stratford	72	8	90	19
Toronto	76	16	91	28
Uxbridge	75	12	93	25
Wallaceburg	73	20	92	31
Welland	73	13	93	28
White River	70	- 16	89	12
Quebec				
Brome	77	11	90	25
Father Point	57	8	78	32
Montreal	78	8	89	28
Quebec	74	2	91	24
Sherbrooke	80	- 1	92	27
Maritime Provinces				
Charlottetown	74	15	80	30
Chatham	78	7	92	27
Dalhousie	76	9	86	23
Fredericton	78	7	92	24
Halifax	80	14	89	30
Moncton	78	9	85	27
St. John	66	11	72	31
St. Stephen	82	9	92	20
Sussex	77	9	90	25
Sydney	75	13	75	29
Yarmouth	72	18	72	28

MAGNETIC OBSERVATIONS

During April the only marked disturbance of the magnetic forces began at 6 o'clock of the 8th and continued until midnight of the 9th. Its amplitude in declination was 1° 18·4′ and in horizontal force more than 501γ. Aurorae of the 2nd and 3rd classes were very generally recorded on the 8th and 9th. From the 15th to 24th the magnets were lightly disturbed and during this period also aurorae were observed in all parts of Canada.

In the month of May no large magnetic storms were recorded but on nearly all days there were disturbed intervals.

Declination

Month	Mean of Month	Max.	Date	Min.	Date	Monthly Range	Amplitudes—Mean Daily: From hourly readings	Amplitudes—Mean Daily: From Means of Extremes
1911	° ′	° ′		° ′		° ′	° ′	° ′
April	6 8·5	6 45·3	9	5 26·9	8	1 18·4	0 8·2	0 20·6
May	6 8·5	6 34·4	7	5 35·8	14	0 58·6	9·5	19·4

Bifilar

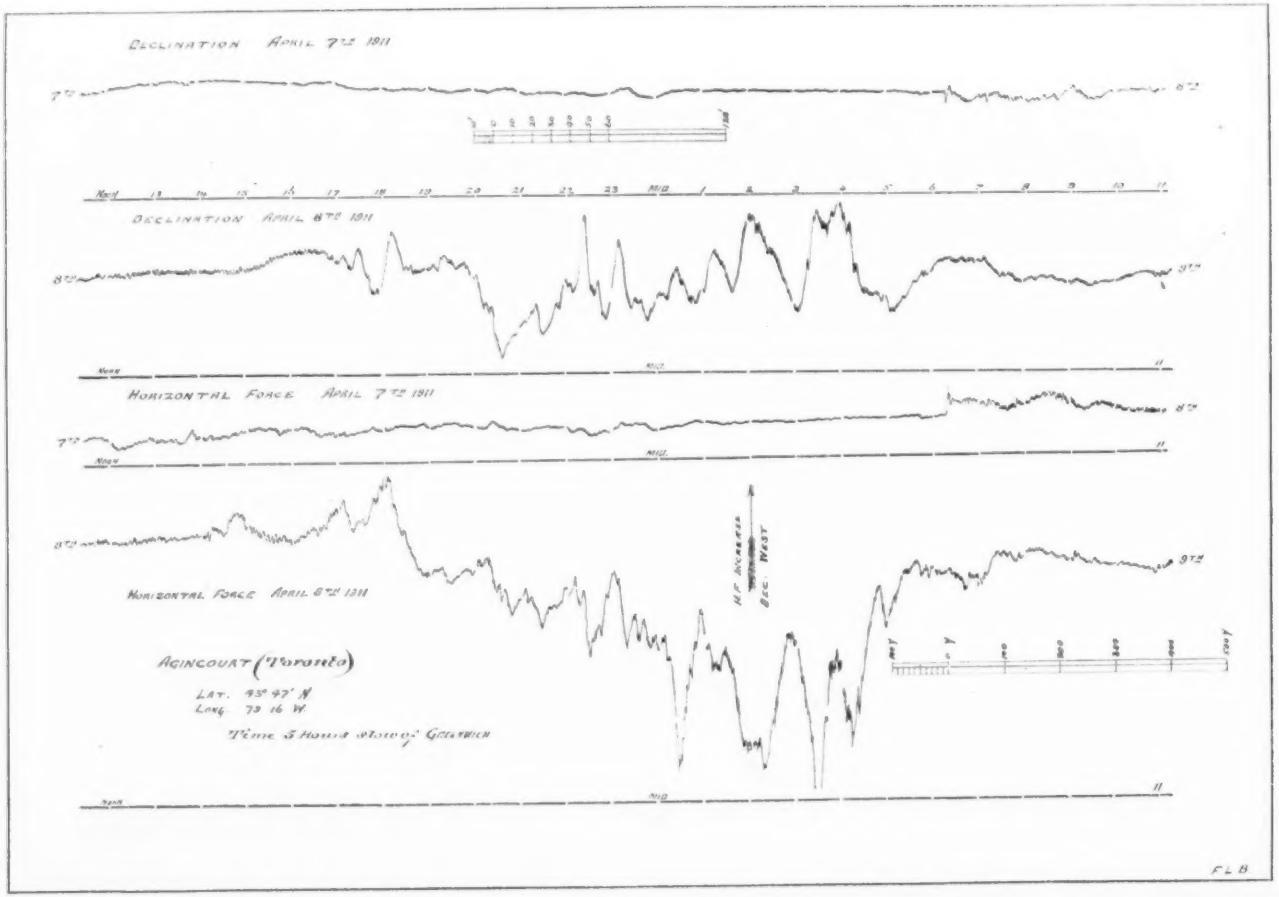
	C.G.S. units							
April	·16209	·16361	8	*·15860	9	·00501	·00033	·00088
May	·16205	·16300	14	·16043	14	·00257	·00037	·00075

* Minimum went below this limit of record.

Inclination

Month	Mean
	° ′
April	74 39·0
May	74 38·4

The accompanying Diagram, on opposite page, shows movements of the magnets during the magnetic disturbance of April 8th and 9th. The times of the beginning of small movements of disturbance are declination $6^h\ 19^m\ 50^s{\cdot}6$; horizontal force $6^h\ 19^m\ 46^s{\cdot}7$.


DECLINATION APRIL 7TH 1911
DECLINATION APRIL 8TH 1911
HORIZONTAL FORCE APRIL 7TH 1911
HORIZONTAL FORCE APRIL 8TH 1911
H.F. INCREASE
DEC. WEST
AGINCOURT (Toronto)
LAT. 43° 47' N
LONG. 79 16 W.
Time 5 Hours slower GREENWICH
F.L.B.

Earthquake Records by the Milne Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors, L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1911		P.T Comm	L.W. Comm.	Max.	End.	Max. Amp	Durat.	Remarks
			h m	h m	h m	h m	mm	h m	
999	Apr.	7	V_1 7 0·5 V_2 7 3·7	7 11·8 7 26·0	7 29·5	8 45·7?	0·7	1 42·0 1 45·2	Small and well defined
1000	"	8	2 41·7			8 45·3	0·05	0 3·6	
1001	"	10	16 28·9		16 30·6	16 44·8?	0·2	0 15·9	Gradual beginning
1002	"	10	No P.T's	18 54·9	19 1·8	19 54·0?	0.8	0 59·1	Suddenly disturbed
1003	"	18	19 10·7	19 16·6	19 35·0	19 56·5	0·2	0 45·8	
1004	"	28	No P.T's	10 8·4	10 8·6	10 32·1	0·3	0 23·7	
1005	May	4	23 49·3	23 58·0	23 59·2 B0 4·8	1 59·0	3·2	2 9·7	Max. soon after L.W.
1006	"	9	19 56·5		19 57·4	20 20·0	0·15	0 23·5	
1007	"	9	22 57·8			22 59·0	0·10	0 1·2	
1008	"	10	0 43·4		0 44·1	0 48·6	0·20	0 5·2	Began suddenly
1009	"	14	21 29·6		21 31·2	21 47·0	1·10	0 17·4	[Spain
1010	"	19	20 52·2		20 53·2	21 9·1	0·30	0 12·9	Prov. of Murcia.
1011	"	25	8 13·0		8 13·7	3 18·8	0·20	0 5·8	Santa Maura, [Ionian Islands

Period 14·6 seconds. 1 mm. = 0″·64.

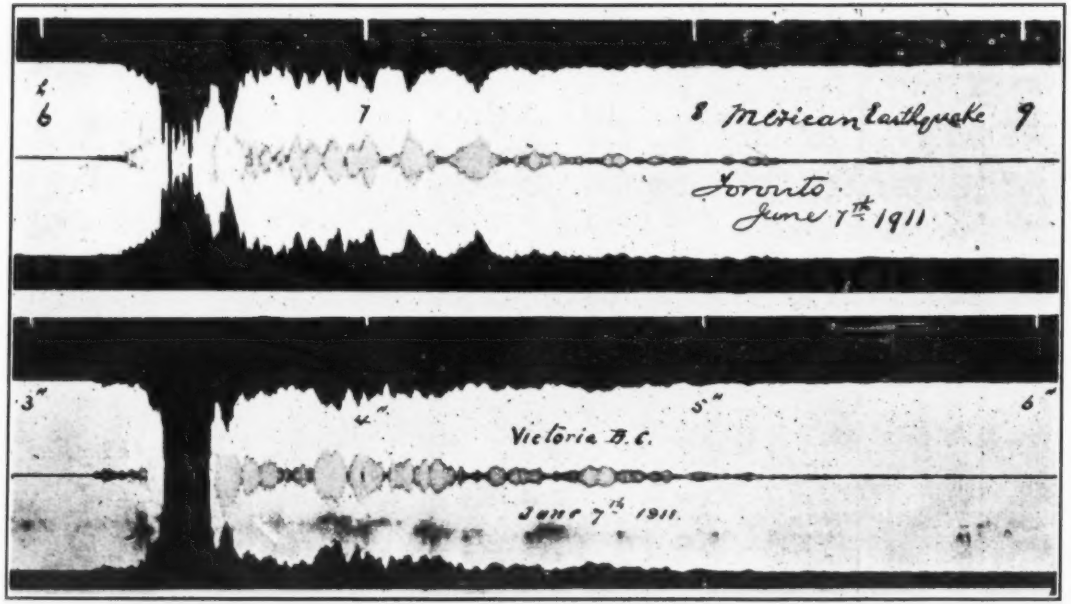
VICTORIA, B. C.

E. B. Reed, Superintendent.

No.	Date 1911		P.T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
			h m	h m	h m	h m	mm.	h m	
1025	Apr.	7	6 57·4	V_2 7 6·9 LW 7 13·5	7 17·2	8 11·2	0·6	1 13·8	
1026	"	10	18 52·0	18 55·0	18 16·0	19 47·0	0·3	0 55·0	
1027	"	17	5 29·3		5 31·4	5 33·7	0·15	0 4·4	Grad. beginning
1028	"	18	19 3·1	19 14·0	19 16·7	19 47·8?	0·3	0 44·7?	[and ending
1029	"	21	3 4·6			3 16·5	0·2	0 11·9	Grad. thickening
1030	"	28	10 11·4		10 15·3	10 20·5	0·1	0 9·1	
1031	May	1	11 23·9		11 25·0	11 29·5	0·05	0 5·6	
1032	"	4	23 45·4	23 53·0	23 54·1 B23 56·2	2 6·4	3·2	2 21·0	Moderate
1033	"	9	19 59·5			20 3·4	0·05	0 3·9	
1034	"	10	0 26·9		0 27·3	1 5·1?	0·8	0 38·2?	Began gradually
	"	14	Attending inst.		Light off				

Period 15 seconds. 1 mm. = 0″·76

J. Y.



		h	m		h	m
Toronto —	V_1	11	9·1	Max	11	23·8
	V_2	11	10·3	Amp. over 20 mm.		
	L W	11	15·2	End	14	41·4

		h	m		h	m
Victoria, B.C. —	V_1	11	9·6	Max.	11	28.8
	V_2	11	11·1	Amp. over 25 mm.		
	L W	11	19·1	End	14	28·5

ASTRONOMICAL NOTES

THE PLACE OF COMETS IN COSMOGONY.— In a paper in *Pub. Ast. Soc. of the Pacific*, No. 136, H. D. Curtis concludes:— The results of the labors of Fayet, Fabry and Strömgren may then be stated: Considering only the influence of Newtonian gravitation and introducing no other forces, all known comet orbits were doubtless originally ellipses; *i. e.*, we are justified in assuming that the entire comet family are permanent members of our system and that none have come in from interstellar space. In conclusion Stromgren draws attention to the need for future computors of definitive orbits themselves to calculate the effect of the earlier perturbations on the eccentricity (in cases where the eccentricity is close to parabolic), for without such calculations the orbits have little value for investigations in cosmogony.

TOTAL SOLAR ECLIPSE OF APRIL 28.— Later telegrams practically corroborate the information which appeared in our last number relative to Dr. Lockyer's expedition. Father Cortie says that thick cirrus clouds persisted at totality, but photographs of the corona and its spectrum were obtained, the corona being characteristic of the sun-spot minimum. Mr. Worthington, who was also at Vavau, says that he got splendid photographs of the inner and outer corona. Apparently the most satisfactory results were obtained by Mr. C. L. Wragge, formerly Meteorologist to the Queensland Government, who saw the eclipse under excellent conditions from Lifuka, Friendly Islands. Hydrogen prominences were seen distinctly as well as the corona as before described.— *Observatory*, 1911.

MECHANICAL PRODUCTION OF STREAMERS SEEN IN THE SOLAR CORONA.—In order to test the theory that the shapes of observed coronal streams may be accounted for on the assumption that they are the natural production of certain defined mechanical forces, Professor J. A. Miller examined the excellent series of corona photographs now available at the Lick Observatory, and he publishes the results of his discussion in No. 4, Vol. XXXIII., of *The Astrophysical Journal*.

If the streamers are formed of particles ejected from the sun under the influence of the solar rotation, of the attraction and of the radiant pressure of the sun, certain shapes should theoretically ensue, and the velocity and direction at any point of the stream can be calculated. Professor Miller has done this, and finds that not only do the observed streamers largely conform with his theoretical results, but he is able to compute and draw theoretical streamers, for the conditions obtaining at any one eclipse, which agree with those actually observed. Various modifications occur, but may be accounted for by reasonable assumptions of modified conditions; for example, the particles at the end of a stream are probably finer than those at the base, and, therefore, the sun,s radiant pressure would act more strongly on them, or it may be that the particles of a stream are moving in a resisting medium which is denser in the inner than in the outer corona, and each of these causes would produce the differences observed between the computed and the observed results.—*Nature*, June 8, 1911.

HEAT AND LIGHT OF METEORITES.—Conclusions from a paper by Rev. M. Davidson, in *Journal British Astronomical Association*, Vol. XXI., No. 7.

Meteorites striking our atmosphere will have their surfaces fused, even at high altitudes, up to 100 miles, say, and if sufficiently large may become visible at that height owing to the heated air forming an envelope. The height at which they will have developed sufficient heat to cause complete volatilisation will depend upon their size, velocity, and angle at which they strike the vertical.

For large masses ranging from a few hundredweights up to 30 tons, this amount of heat can only be generated when they have reached lower altitudes, from 23 to 45 miles, according to velocity, size and angle with which they strike.

Small meteorites like grains of sand or shot can develop this heat in the higher regions, up to about 70 miles, and might, therefore, be volatilised at this height.

For a height of 150 miles, if volatilisation occurs there, the meteorite is possibly in a gaseous state.

The resistance of the atmosphere to the motion of bodies becomes greater as they diminish in size, and the temperature produced in them by friction against the air increases.

Nova Lacertæ.—In *Monthly Notices* R. A. S. for January, 1911. There are several papers on this subject. The Rev. T. E. Espin describes its discovery and how the spectroscope revealed the presence of bright lines where no variable star had been known to exist. It was first seen in twilight and estimated at 8·0 mag., but was in reality a little under 7·0 mag. The spectroscope showed a bright line, presumed to be F, flanked on the more refrangible side by a great band, making the spectrum perfectly discontinuous; then a bright band, and in the violet a line probably from hydrogen; in the yellow was a bright line, and between it and F three bands with bright flutings between them. On the less refrangible side of the yellow line was a strong band, and further on the red possibly a bright line. Mr. A. R. Hincks gives observations made with the photographs from the Sheepshanks equatorial, and observations of the spectrum made with a small direct-vision prism held over the eyepiece. Mr. F. A. Bellamy gives the position of the Nova as determined from photographs taken at the University Observatory, Oxford.

Professor S. A. Mitchell, in the *Scientific American*, Vol. CIV., No. 9, discusses not only the apparition of Nova Lacertæ but in addition the nature of novæ in general. Of the 36 new stars discovered since that of Hipparchus in B.C. 134, 18 have appeared since 1885; 15 of these have been first found on photographs, and 14 of them on plates taken at Harvard or Arequipa.

Professor Mitchell finds that both the "pressure" and the "collision" theories leave much to be desired, and favors the passage of a rapidly moving star through a previously unknown nebula.—*Journal B. A. A.*, No. 7.

Motion of Calcium Vapor Over Sun-Spots.—General conclusions of a paper by Charles E. St. John. *Mount Wilson Solar Observatory Contribution*, No. 54, (March, 1911).

1. In the great majority of sun-spots the calcium vapor is descending in the umbræ with velocities varying from 0·68 km per second to 2·2 km per second. This result is obtained from the usual bright reversal over the umbræ and also from the absorption line when present. Occasionally the calcium vapor is rising in the umbræ.

2. Over the penumbræ of spots the calcium vapor which is the source of the bright line K_3 has little, if any, vertical motion. The calcium vapor producing the absorption line is descending with approximately the same mean velocity as over the general disk.

3. Over flocculi surrounding spots the emitting vapor shows a very slight but doubtful upward motion. The mean wave-length for K_3 over the central flocculi is 3933·665 Å compared with 3933·667 Å in the arc, an agreement within the errors of measurement. The absorbing vapor, the source of the K_3 line, is descending with the same mean velocity as over the general disk.

4. Over circumfloccular regions the upper layer of absorbing calcium vapor is descending with practically the same mean velocity as over the general disk, and does not show evidence of a local system of circulation involving the flocculi and their immediate surroundings.

5. A radial motion of the calcium vapor inward across the penumbræ is shown both by the emitting and absorbing vapor. The velocity is higher for the absorbing vapor than for the emitting vapor.

6. A rotary motion of the calcium vapor around the umbræ of spots is an occasional phenomenon, and is shown by the dis-

placements of both the absorption line and the bright line. The velocity is higher in the case of the absorbing vapor than in the case of the emitting vapor.

7. The combination of the radial motion inward and the rotary motion results in a spiral or a vortical motion converging upon the umbra. The direction of rotation does not depend upon whether the spot is north or south of the sun's equator. The disturbance appears to originate in the high-level absorbing vapor and to work downward, involving the emitting layer.

8. The phenomenon of a dark absorption line appearing in one of the K_2 components, or beyond their outer edges, while the K_1 line is undisturbed, is interpreted as being caused by detached masses of relatively cool calcium vapor high above the chromosphere, and in more or less rapid motion, that is, by prominences projected against the sun's disk.

9. In addition to the general circulation of the calcium vapor shown by the ascent of the emitting vapor and the descent of the absorbing vapor over the general surface of the sun, there appears to be a local system in which the emitting vapor rises around the flocculi, flows across the penumbra, and is then drawn downward into the umbra with or without vortical motion. There is very slight evidence, if any, of its rising from the interior of the sun through the faculæ, except in the case of eruptions.

10. The intensity of the bright K_2 line over flocculi is less than that of the continuous spectrum. The apparent weakness of the K_2 line in the spectrum of the centre of the sun is due mainly to the slight difference between it and the background of the K_1 line. Its apparent increase of intensity at the limb is due in the main to the greater absorption in the K_1 and K_3 lines which raises the K_2 line into relief without much actual increase of intensity.

11. The relative intensities of the K_1, K_2 and K_3 lines may be explained by the great differences in their radiation coefficients and the consequent different depths in the solar atmosphere from which light of their respective wave-lengths reaches the surface owing to the selective absorption. The occurrence of the bright

emission line K, would be favored by the scattering of the light from the still lower layer.

12. The results for different levels obtained by the spectro-heliograph find a possible explanation through considering the underlying faculæ as sources of disturbance propagated into the overlying masses of calcium vapor and increasing in different degrees the radiation coefficients of the components of the K line.

Nature of Inertia.—Among the papers read at the annual general meeting of the American Philosophical Society in Philadelphia in April this year, was one by Professor H. A. Wilson, of McGill University, Montreal, dealing with the constitution of the Atom. In which he said:—The general conclusion seems to be that the atom of matter, groups of which compose the molecules of different substances, is built up of much smaller parts, called electrons, identical with the smallest unit of negative electricity. It was also explained how it is possible to estimate the actual number of electrons in any particular atom. As the inertia of an electron emitted from an atom of a radio-active substance, such as radium, has been experimentally proved to be a function of its speed, the evidence is strong that all inertia or mass may be electro-dynamic in its nature.—*Nature*, June 15.

Migrating Stars.—Henkle finds that β, γ, δ, ϵ, ζ, in Ursa Major and Sirius are diverging from the same point of a sphere and β Auriga, 37 Ursa Majoris, δ Leonis and α Corona Borealis are as a group, moving towards a vacant region in the Lynx at the rate of about 10 miles per second.

Dr. Stroovant finds that α Cassiopeia, β Persei α Persei, α Scorpii, γ Cygni α and ϵ Pegasi are all moving towards an area 14° radius at the rate of from 6 to 12 miles per second. The sun is moving towards this group at about 11 miles per second. —*Journal B. A. A.*, No. 4.

Wolf's Comet.—Wolf's Comet was observed on June 19th by Professor Max Wolf, at Heidelberg, on its return this year. This comet has a period of a little less than seven years. First

observed by Wolf in 1884. At perihelion passage the comet is about 140 million miles from the sun and at aphelion 450 millions.

A DISPATCH from Harvard College Observatory announces that a comet discovered by Kiess, was observed by him on July 6th in R. A. $4^h\ 51^m\ 51^s$. Declination $+\ 35°\ 15'\ 02''$. Visible with an opera glass, moving south west, with short tail, also observed on July 7th, R. A. $4^h\ 50^m\ 05^s$, Declination $+\ 35°\ 07'\ 41''$; July 8th, R. A. $4^h\ 48^m\ 21^s$, Dec. $+\ 34°\ 58'\ 43''$; observed at U.S. Naval Observatory, July 9th, R. A. $4^h\ 46^m\ 51^s$, Dec. $+\ 34°\ 50'\ 55''$ and at Kiel, Germany, on same day.

This would indicate the comet to be near a faint star in the left foot of Auriga, 12° south of Capella and about 20° north of Aldebaran the bright star in Taurus.

TIDAL ACTIONS.—Double stars are among the most beautiful of telescopic objects, as everyone with a small telescope knows. Why do they exist? Some time since Sir George Darwin and Poincaré showed the mechanical importance of tidal action in the evolution of the heavenly bodies; how a body spinning faster as it contracted upon itself might ultimately split into two parts, and that then the tides raised in each by the other would push the pair farther apart, at the same time rendering their orbits more and more eccentric. Dr. T. J. J. See applied this principle to the case of double stars, showing how much more eccentric than the planetary orbits were the orbits of the visual double stars; he suggested that tidal action had accomplished this.

"Now, as a coincidence, comes an interesting observational sequel: the recent corroboration of such a genesis by the stars themselves. Campbell, Schlesinger, Baker, Russel and others have shown that as the size of the orbit increases its eccentricity increases too. In other words, while double stars are still young in their evolution and consequently near together, their orbits are circular; then, as tidal action acts, just those concomitant effects are produced which theory predicted."—*Pub. Ast. Soc. of the Pacific*, No. 136.

See this JOURNAL, January, 1909, p. 22 and TRANSACTIONS 1901, p. 94.

J. R. C.

BOOK REVIEWS

Annuaire Astronomique de l' Observatoire Royale de Belgique, 1912.

The ephemeris for the year 1912, published by the Royal Observatory of Belgium, retains the features that have given the volumes for earlier years a distinctive place among publications of this kind. While less ambitious than the official Almanacs of England, France, Germany and the United States, equal care is shown in the matter of compilation and editing. The ephemerides of the sun and moon are followed by an interesting and useful section in which are given the elements of the planetary system and the predictions for the year 1912. An ample list of star positions is given, as well as the usual particulars as to eclipses and occultations. The reference tables (tables diverses) are excellently selected and arranged, while the notes on the measure of time and on recent progress in astronomy have a certain succinct completeness.

A List of Books on the History of Science, in the JOHN CRERAR LIBRARY, (Chicago).

The Directors of the John Crerar Library in issuing a catalogue of that important section of the library concerned with the history of science have placed students and investigators under a great obligation to them. So extensive is the collection that one may well turn to this catalogue as to a bibliography for information in regard to the literature of any special department of science. The list will have a special value for those who are sufficiently near to Chicago to make use of the library.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

Query

How is precession of the equinox caused? I cannot quite see why the First Point of Aries is not always the First Point of Aries. I can see how the change in the earth's position would change the declination of a star, but not why, if one constellation be chosen for the zero for measuring right ascension, it should not remain zero. A Member.

Answer

In order to obtain a clear idea of the meaning of the First of Aries and the precession of the equinoxes, we must be able to separate the effects due to the earth's daily rotation and to its annual motion in space. Imagine yourself stationed off at some point away from the earth, and consider what you will see. The earth revolves about the sun, and the plane containing the centres of the earth and the sun is the ecliptic plane. The great circle in which this plane cuts the sky is the *ecliptic*, and the points in the sky distant 90° from it are the poles of the ecliptic.

Again, the earth's axis points in a definite direction, and the plane passing through its equator, when extended, cuts the sky in a great circle which is called the *celestial equator*. The two points where the ecliptic and the celestial equator cut are the equinoxes, one being known as the First of Aries and the other as the First of Libra. Now the earth, as it spins about on its axis, does not always keep its axis pointing in the same direction, but it has a slow majestic motion amongst the stars, describing a circle about the pole of the ecliptic in 26,000 years. It is evident that if the axis moves as stated, the plane of the equator also moves, and so the two points in which the celestial equator cuts the ecliptic must also move. This motion is called the precession of the equinoxes. The equinoxes move westward along the

ecliptic at the rate of 52″ of arc per year or 360° in 16,000 years.

It would be a great advantage to have a point to measure from which is absolutely fixed, but in the operations of practical astronomy it is very convenient to use the First of Aries as a point of reference. It is true that (neglecting the extremely small proper motions) the positions of the stars are *fixed* relative to each other, and so if a certain star were taken as zero it would remain our zero as far as fixity is concerned. But there is no other point so convenient as the First of Aries, even though allowance has to be made for its motion.

Query

What is meant by the Dog Days and why is Sirius called the Dog Star?—C. C.

Answer

The best answer that I can give to this query is to be found in Flammarion's "Astronomical Myths," translated by Blake, pages 74-5, as follows:—

Sirius.—This star seems to have been intimately connected with Egypt, and to have derived its name—as well as the otherwise unimportant constellation it forms part of—from that country, and in this way:—

The overflowing of the Nile was always preceded by an Etesian wind, which, blowing from north to south about the time of the passage of the sun beneath the stars of the Crab, drove the mists to the south, and accumulated them over the country whence the Nile takes its source, causing abundant rains, and hence the flood. The greatest importance attached to the foretelling the time of this event, so that people might be ready with their provisions and their places of security. The moon was of no use for this purpose, but the stars were, for the inundation commenced when the sun was in the stars of the Lion. At this time the stars of the Crab just appeared in the morning, but with them, at some distance from the ecliptic, the bright star Sirius also rose. The morning rising of this star was a sure precursor of the inundation. It seemed to them to be the warning star, by whose first appearance they were to be ready to move to safer spots, and thus acted for each family the part of a faithful dog. Whence they gave it the name of the Dog, or Monitor, in Egyptian *Anubis*, in Phœnician Haunobeach, and it is still the Dog-Star, Caniculus, and its rising commences our *dog-days*. The intimate connection between the rising of this star and the rising of the Nile led people to call it also the Nile Star, or simply the Nile: in Egyptian and Hebrew, *Sihor*; in Greek Σοθίς; in Latin, *Sirius*.

Observations on the Aurora

The interesting observations on the Aurora recorded in "Notes and Queries" in the last issue have drawn from the Society's oldest member, Mr. Andrew Elvins, (who celebrated his 88th birthday on May 4, 1911), some observations which he placed on paper in March, 1871, and which he has put in my hands. Mr. Elvins' views are in large part based on his own observations, and though forty years old are worth recording here. They are as follows:—

The Aurora

1. As seen in Canada, a dark cloud, or bank of dense haze seems to rest on the horizon toward the north. This bank is usually highest just under the pole, or due north, but it is sometimes a little east or west of this point; stars can sometimes be seen through this haze, but their lustre is greatly diminished and on some occasions they are rendered invisible altogether.

2. Resting upon this arch, or coming up from behind it, a bright glow forming an arch of light, seems to surmount the dark bank, and is thus seen the more plainly by contrast. This arch is sometimes near the horizon, sometimes it rises far into the sky, and at other times two or even three arches are seen one above the other.

3. From the upper part of the dark bank, or out from one of the bright arches, rays or columns of light pass upward toward the zenith; sometimes the motion is rapid, sometimes slow; the columns or streamers have also a horizontal motion, their lower extremities sweeping eastward and sometimes in the opposite direction.

4. The rays or columns of light sometimes pass upward and meet near the zenith, or at least they seem to do so. A crown of light is formed. From this corona streamers sometimes spread out in all directions, like fiery ribs of the celestial dome.

5. The auroral light does not always appear as streamers or columns. Sometimes it is seen as clouds or patches of light in various parts of the heavens, breaking out again and again in the same spot and having the same general form as the previous patch before it faded away.

6. (And this I think too much overlooked). The auroral light sometimes instead of rising from the north, passes in a straight line or stream from east to west, spanning the whole heavens, and usually passing a little south of the zenith, crossing the point where the corona forms when it is visible. Such streams have a wavy motion, and this motion is always westward.

7. The color of auroral light is usually yellow or yellowish-green, but it is frequently red from a bright carmine to the deepest blood color. In some displays almost all the colors of the rainbow are visible.

8. A luminous haze or glow is sometimes seen to fill the atmosphere during the aurora. (Of this feature of the aurora of April 15, 1869, Professor Kingston says: "Throughout the night a generally diffused luminosity prevailed such as is commonly seen with a full moon and hazy sky. This was evidently not occasioned by the moon, which was scarcely four days old, and was low on the horizon, but was part of the aurora itself, the brilliancy of whose more active features it greatly impaired."

9. Clouds are frequently seen to form beneath auroræ; a dark, hazy, misty cloud sometimes renders the aurora scarcely visible itself.

10. Auroræ have been seen during daylight, appearing at such times as an extremely light cloud or vapor and shining out as a bright aurora as soon as night approached.

11. The moon and planets are sometimes surrounded by a halo, when their light passes through auroral matter.

12. The height of auroræ varies greatly. Sometimes it seems to fill our atmosphere, and observations prove it to be in some cases thousands of miles above the earth's surface. Usually, however, the height is between 100 and 500 miles.

13. The light of the aurora has been examined spectroscopically by Angström, Zöllner, Piazzi. Smyth, and our townsman D. K. Winder, and in every case the aurora gives a spectrum of *bright lines*.

14. The magnetic needle is usually greatly disturbed during auroral displays, so much so that the instrument will often lead us to expect an approaching aurora.

15. Auroral displays are periodical. We get the most about the time of the equinoxes, or in March and April, and September and November; and in addition to this we get auroræ more brilliant and frequent at the time when spots are most numerous on the sun's surface, and when the sun has few spots we have few auroræ.

16. Mr. Chase has shown that rain frequently follows auroral displays, and Mr. Winder states that such displays are usually preceded by a fall of temperature.

17. The usual spectrum of the aurora consists of bright lines; the brightest line (5579 Angström's wave-length) in the greenish yellow part of the spectrum, is sometimes seen alone, though usually others are visible; but they are generally faint. Some observers, however, state that they have seen bright lines crossing a continuous spectrum as a background.

18. The moon and planets have been seen surrounded with a halo, when their light has passed through auroral streamers and patches of auroral light.

Death of Mrs. Fleming

The readers of the Journal will regret to learn of the death of Mrs. Willamina Paton Fleming on May 21 at the age of 54

years. For some years Mrs. Fleming has been Curator of the great collection of astronomical photographs at Harvard College Observatory, and her examination of the negatives taken at the Observatory has led to many important discoveries. Mrs. Fleming was at the Solar Conference in California in 1910, and her portrait appears on several of the illustrations accompanying the account of that gathering printed last autumn in this JOURNAL.

THE R. A. S. C. GOLD MEDAL

The Society annually offers to the University of Toronto a gold medal for the highest stand in first-class honors in the course in Astronomy and Physics. The recipients up to the present, and the positions held by them, are as follows:—

1907 — W. E. Harper, at the Dominion Astronomical Observatory, Ottawa.

1908 — R. M. Motherwell, at the same institution.

1909 — Reynold Young, Fellow at the Lick Observatory, since graduation

1910 — R. J. McDiarmid, during 1910-11 Fellow at Allegheny Observatory; recently appointed to the Dominion Observatory.

1911 — R. S. Sheppard, Assistant at the Lick Observatory.

FROM EXAMINATION PAPERS

Wandering of the Pole. This means that the pole does not stay in one position. The whole sphere wabbles hence the pole. For example we have librication.

[*The Sun*]. Its specific heat is said to be about 6000° centigrade and would melt ice at the rate of 40 ft. per minute.

The Moon is a reflective body.

C. A. C.